POSTHARVEST LOSSES AND CHANGES IN QUALITY OF VEGETABLES FROM RETAIL TO CONSUMER: A CASE STUDY OF TOMATO, CABBAGE AND CARROT

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Thesis presented in partial fulfilment of the requirements for the degree of

MASTER OF SCIENCE IN FOOD SCIENCE

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December 2012

DECLARATION

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ABSTRACT

Postharvest losses of three different vegetables (tomato - a fruit, cabbage - a leaf and carrot - a root vegetable) were investigated directly after retail purchasing and during consumer simulated storage. To conduct this study, three retail outlets (2 supermarkets and an outdoor market) were selected in Stellenbosch, South Africa. Retail prices of each vegetable were recorded from each respective Outlet. Surrounding environmental conditions (air temperature and relative humidity) at retail and during simulated consumer storage were also monitored. Vegetable postharvest losses were determined by quantifying the incidence of physical loss and changes in physico-chemical properties (colour, firmness, weight loss, ascorbic acid, total pigments, total soluble solids, titratable acid and proximate composition) over time. The percentage losses observed were then used to estimate the associated economic and environmental resource impacts of postharvest vegetable losses at the national level.

Vegetable losses immediately at retail purchase were 14.56%, 21.21% and 17.93% for tomato, cabbage and carrot, respectively. The estimated combined volume lost for all three vegetables at national level was approximately 26 460 t valued at R33.70 million. Overall economic loss was highest for tomatoes and least for carrots. The magnitude of the losses observed differed for all the outlets. Vegetable losses were mostly high for the produce from the outdoor market compared to the supermarkets during storage. Throughout the whole trial, mechanical damage accounted for at least 50 to 70% of the losses while the remainder was due to decay and insect damage.

Post retail storage temperature; ambient (22 – 25 ºC) vs. cold store (0 ºC and 10 –12 ºC) had a significant ($P<0.05$) effect on the vegetable losses. This was for both quantitative and qualitative attributes. Losses for tomato and cabbage were 18.52% and 16.67% after 3 days while carrot losses were 11.83% at 7 days after having been kept in the recommended respective cold storage temperatures. Ambient storage losses were also lowest for carrots at 22.53% after 7 days, while tomato and cabbage losses stood at 24.27% and 34.34% after 3 days of storage, respectively. Vegetable firmness generally decreased while weight loss increased with storage time. Colour development increased favourably at ambient temperature for the tomato whereas for cabbage and carrot better colour retention was observed

in the cold storage. Chemical changes for all three vegetables were also most pronounced at ambient temperature with significant ($P<0.05$) losses observed for ascorbic acid. Changes were also noted for total pigments, soluble solids and acidity, however there was no common significant trend for all three vegetables.

Estimates of carbon dioxide emissions reveal that postharvest vegetable losses contribute to unwarranted emissions of at least 1.37 – 13.77 million tonnes of carbon dioxide equivalents ($CO_{2eq.}$) at the national level. The losses are also accompanied by wastage of approximately 3.74 – 4.35 million m^3 of fresh water as well as 14.79 – 111.63 million MJ of fossil energy. The vegetable with highest production volumes and retail price was the tomato and accordingly, its postharvest losses had the severest environmental and resource impacts.

UITTRESKEL

Die ná-oes-verliese van drie verskillende groentes (tamatie – ’n vrug, kool – ’n blaar, en wortel – ’n wortelgroente) is direk ná kleinhandelaankope en tydens gesimuleerde verbruikersberging ondersoek. Ten einde hierdie studie uit te voer, is drie kleinhandelsafsetpunte (twee supermarkte en ’n opelugmark) in Stellenbosch, Suid-Afrika gekies. Die kleinhandelpryse van elke groente van die drie onderskeie afsetpunte is opgeteken. Omliggende omgewingstoestande (lugtemperatuur en relatiewe humiditeit) tydens verkope en gesimuleerde verbruikersberging is ook gemonitor. Die ná-oes-verliese van die groentes is bepaal deur die voorkoms van fisiese verlies en veranderings in fisio-chemiese eienskappe (kleur, fermheid, gewigsverlies, askorbiensuur, totale pigmente, totale oplosbare suikers, titreerbare suur en algemene samestelling) met verloop van tyd te versyfer. Die waargenome persentasie verliese is gebruik om die geassosieerde ekonomiese en omgewingshulpbron-impak van ná-oes-groenteverliese op nasionale vlak te beraam.

Groenteverliese met kleinhandelaankope was onderskeidelik 14.56%, 21.21% en 17.93% vir tamaties, kool en wortels. Die beraamde saamgestelde volume verlies vir al drie groentes op nasionale vlak was ongeveer 26 460 t, met ’n waarde van R33.70 miljoen. Die algehele ekonomiese verlies was die hoogste vir tamaties en die laagste vir wortels. Die omvang van die waargenome verliese het vir al die afsetpunte verskil. Groenteverliese tydens berging was hoofsaaklik hoog vir die produkte van die opelugmark in vergelyking met dié van die supermark. Tydens die algehele proefneming was meganiese skade verantwoordelik vir ten minste 50 tot 70% van die verliese, terwyl die res aan verrotting en insekskade toegeskryf kan word.

Bergingstemperatuur ná kleinhandelaankope: omgewingstemperatuur (22 – 25 ºC) vs. koue berging (0 ºC en 10–12 ºC) het ’n beduidende ($P < 0.05$) uitwerking op groenteverlies gehad. Dit geld vir sowel kwantitatiewe as kwalitatiewe attribute. Verliese vir tamaties en kool was onderskeidelik 18.52% en 16.67% ná drie dae, terwyl dit vir wortels 11.83% teen sewe dae was nadat dit teen die aanbevole onderskeie koue bergingstemperature geberg is. Bergingsverliese in omgewingstemperatuur was ook die laagste vir wortels teen 22.53% ná sewe dae, terwyl die verlies van tamaties en kool onderskeidelik 24.27% en 34.34% was ná drie dae se berging. Die fermheid van die groente het oor die algemeen met die duur

van berging verminder, terwyl gewigsverlies toegeneem het. Kleurontwikkeling het gunstig teen omgewingstemperatuur toegeneem vir die tamaties, terwyl die kleur van kool en wortels beter in die koue berging behou is. Chemiese veranderinge vir al drie groente was die sterkste teen omgewingstemperatuur, met beduidende ($P < 0.05$) verliese van askorbiensuur wat waargeneem is. Veranderinge is ook gemerk rakende totale pigmente, oplosbare vaste stowwe en suurgehalte. Daar was egter geen algemene beduidende neiging vir al drie groentes nie.

Beramings van koolstofvrystellings toon dat ná-oes-groenteverlies tot ongeoorloofde vrystelling van ten minste 1.37 tot 13.77 miljoen ton koolstofekwivalente ($CO_{2eq.}$) op nasionale vlak bydra. Die verliese gaan ook gepaard met verbruik van ongeveer 3.74 tot 4.35 miljoen m^3 vars water asook 14.79 tot 111.63 miljoen MJ fossielbrandstof. Die groente met die hoogste produksievolume en kleinhandelprys was die tamaties, en gevolglik het tamaties se ná-oes-verliese die ernstigste impak op die omgewing en op hulpbronne.

To my Family

ACKNOWLEDGEMENTS

I wish to express my sincere gratitude and appreciation to the following:

Prof. Umezuruike Linus Opara, as study leader, for granting me the opportunity to do this MSc, under his guidance, patience and positive criticism;

Dr. Gunnar Sigge as co-study leader, for his guidance, and support during the course of this research;

The South African Research Chairs Initiative of the Department of Science and Technology and National Research Foundation;

The University of Stellenbosch University Security Initiative for the award of bursary;

All the personnel from the Postharvest Technology Research Laboratory of the South African Research Chair in Postharvest Technology for assisting me in my physical measurements and for their morale support;

Cheusi for your undying devotion and committed support;

My mother and siblings for their love and profuse encouragement;

Most Importantly my Heavenly Father for walking with me all the way and never leaving my side.

CONTENTS

Language and style used in this thesis are in accordance with the requirements of the International Journal of Food Science and Technology. This thesis represents a compilation of manuscripts where each chapter is an individual entity and some repetition between chapters has, therefore, been unavoidable.

Chapter 1

INTRODUCTION

A diversity of vegetables is grown all over the world for their nutritional value, taste and cuisine. Global vegetable production was 965.65 million tonnes in 2010 and continues to grow in order to meet an ever increasing consumer demand (FAOSTAT, 2012). A limited volume of fresh vegetables is traded globally, with just 3% comprising the export market in 2004 (Baas, 2006). This indicates a high level of self sufficiency for most countries especially those ranked in the top 50, including South Africa. Improved productivity of vegetables can be attributed to widespread use of mechanisation, improved quality inputs (e.g. seeds), technological advances and better cold chain management skills (Hodges *et al*., 2011).

Consumption of vegetables is important for preventing non- communicable diseases (NCD) including malnutrition and obesity related disorders (FAO, 2010; Kitinoja, 2010; Keatinge *et al.,* 2011). Nevertheless, accessibility to a vegetable rich diet remains a challenge. This is primarily a problem in the developing world. In South Africa and in other developing countries, addressing the problem of food and nutrition security remains a key priority. At least 2 – 3 billion people are estimated to be suffering from malnutrition across the globe, while 925 million people suffer from hunger, representing almost 16% of the population of developing countries (FAO, 2009; FAO, 2010).

World population is increasing as the natural resources continue to be depleted at an alarming rate. Economic and productivity growth alone are not sufficient to eliminate hunger and provide vegetable sufficiency within an acceptable period of time (FAO, 2010). Food security at local, regional and global levels will need to be realised in the face of emerging challenges such as rapid population growth and climate change (Delian *et al*., 2011). Postharvest losses are among the major problems threatening the sustainable use of the limited natural resources for food production (Kitijonga, 2010). Globally, up to one third of all fresh produce, which is about 1.3 billion tonnes never reaches the consumer and is lost along the postharvest supply chain (Gustavsson *et al*., 2011). Regardless of their location, postharvest losses have a cumulative effect, contributing to waste and food insufficiency (Kader, 2005, Kader, 2010). Tapping into the potential to reduce postharvest losses can be one efficient measure to address the tensions between production and food sufficiency.

Retail trade constitutes an important industry across the globe, by providing a diversity of vegetable products at competitive prices. Vegetable suppliers including growers, traders and processors are mainly governed by the requirements of large retail chains and food service companies with regards to the quality and coordinated movement of product flows beyond the farm gate (*Parfitt et al*., 2010). Therefore it is at the retail stage that the cumulative effect of postharvest losses across the supply chain is determined (Nunes *et al.,* 2009). The large quantities of vegetables on retail displays, and wide range of brand names promotes surplus supplies. This often leads to food waste with some of the products reaching their “sell by” date before being sold (Gustavsson *et al*., 2011). Produce that has to be sold at reduced value or doesn’t get sold at all constitutes to postharvest losses for the retailer (Stuart, 2009). Post retail storage losses at the consumer level usually result from storage temperature abuse and or surplus purchasing resulting in spoilage of vegetables before consumption (WRAP, 2011).

Limited data exists on postharvest vegetable losses a separate food entity (Genova *et al*., 2006; Weinberger *et al*., 2008; Kitinoja, 2010). To guide policy and address the problem of postharvest vegetable losses, reliable data on the current magnitude and sources of the losses along the supply chain must be determined (Newman *et al.,* 2008; Weinberger *et al.,* 2008). Most postharvest loss researches focus on vegetable physical losses alone (NAS, 1978; Kader, 2005; Kitinoja, 2010; FAO, 2011). However it is also imperative to investigate the physical losses in combination with nutritional value changes during postharvest, as well as the environment and resource use efficiency associated with the vegetable losses. This in turn provides comprehensive information on the nature and overall nutritional, economic and environmental impacts of the losses.

The main objective of this study is to quantify the magnitude of postharvest losses of vegetables at retail purchasing and during consumer simulated storage. The specific aims were to; (i) estimate the incidence of vegetable postharvest physical losses, (ii) quantify the changes in physico-chemical properties related to quality during storage, and (iii) estimate the economic and environmental impacts of the losses. Case studies of three different vegetables (tomato, a fruit vegetable; cabbage, a leafy vegetable and carrot, a root vegetable), from three retail outlets were used to simulate the handling of vegetables from retail outlets to consumer household level. The results obtained on magnitude of physical postharvest losses were utilised to estimate the environmental and resource impacts of postharvest vegetable losses.

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Chapter 2

LITERATURE REVIEW

A. BACKGROUND ON VEGETABLES

Vegetables can be defined as any edible and usually succulent, portion of plant or part of a plant (Saha, 2002) other than a sweet fruit or seed with a savoury flavour (Hui *et al.,* 2004). These edible portions include roots, tubers, stems, buds, bulbs, leaves, flowers, seeds and fruits (Saha, 2002). Vegetables are diverse in their morphological structure, nutritional composition and general physiology. Therefore the requirements and recommendations for maximum postharvest life vary among the different groups of vegetable commodities (Sudheer & Indira, 2007). By nature all vegetables have a high moisture content which renders them to be highly perishable such, that if not handled properly, a high-value nutritious product can deteriorate and decay in a matter of days or even hours (Kader, 2002).

Vegetables are an important component of the human diet contributing to food and nutritional security. In the absence of essential vitamins, deficiency diseases can develop that can contribute to an overall state of physical decline and the inability to fight off particular illnesses (WHO-FAO, 2005). Vitamins are organic compounds found in natural foods like vegetables either as such or as utilisable "precursors" needed for the maintenance of the skin, mucous membranes, bones, teeth and hair as well as vision and reproduction (Chatterjea & Shinde, 2007). Poor nutrient diets have the potential to cause prolonged vitamin deficiencies, leading to painful and potentially deadly diseases (Rosen & Shapouri, 2008).

Vegetables are rich sources of micronutrients, provitamin-A, C, and E as well as folate, minerals and dietary fibre, (Table 1) that are necessary for growth, development and a healthy immune system, (Story & Stang, 2005; Marcoe *et al.,* 2006; Maillot *et al.,* 2007; Rolfes *et al.,* 2008). As a food group, vegetables contain many phytochemicals such as lycopene, beta-cryptoxanthin, zeaxanthin, and beta-carotene which have medicinal properties (Hung *et al.,* 2004). Vegetables also supply some mineral elements which other food materials are deficient in and help neutralise acid substances produced in the course of digestion of meats, cheese and high energy meals (Saha, 2002). This study will focus on tomato a fruit vegetable,

Table 1 Nutrient profiles for food group and subgroup composites (Story & Stang 2005; Marcoe *et al.*, 2006; Maillot *et al.*, 2007)

Nutrient	**Nutrient RDA**			**Vegetable Subgroups***					**Grains***			
	Male	Female	Fruits	Dark-green	Orange	Dry Beans	Starchy	Other	Whole	Refined	Meat*	Milk**
Energy kcal	2200	1800	59	20	32	114	73	18	308	332	196	42
Protein, g	70	50	0.7	1.6	0.7	8.0	1.7	0.9	9.6	8.8	28	4.2
CHO, g	130	130	14.7	3.9	7.4	19.2	16.8	3.9	62.4	63.2	0.8	6.1
Total Fat	25	20	0.2	0.2	0.1	1.0	0.2	0.2	4.4	4.4	8.0	0.1
Dietary Fibre, g	30	30	1.1	2.1	2.1	6.0	1.7	1.1	9.6	2.8	0.0	0.0
Vitamin A, μg RAE	800	600	16	167	554	0	2	13	104	20	68	35
Vitamin E, mg AT	12	12	0.2	1.0	0.6	0.6	0.0	0.4	0.4	0.4	0.4	0.0
Vitamin C, mg	75	90	25	30	5	0	6	9	4	0	0	0
Thiamine, mg	1.30	1.10	0.06	0.05	0.05	0.14	0.09	0.04	0.52	0.56	0.36	0.11
Riboflavin, mg	1.6	1.5	0.03	0.10	0.04	0.05	0.03	0.04	0.44	0.4	0.28	0.23
Niacin, mg	14	11	0.3	0.4	0.6	0.4	1.1	0.5	5.6	5.6	5.6	0.1
Folate, μg DFE	330	300	24	81	10	111	14	14	200	236	8	48
Iron, mg	9	16	0.2	1.0	0.3	2.3	0.4	0.6	7.2	4.8	2.4	0.05
Calcium, mg	900	900	11	50	23	57	8	21	104	120	12	153
Magnesium, mg	420	360	12	25	9	46	19	10	108	28	28	14
Zinc, mg	12	10	0.1	0.3	0.2	1.0	0.3	0.2	3.6	0.8	5.6	0.05
Potassium, mg	3100	3100	213	229	214	363	286	162	364	116	420	191

* 90 g
** 120 mL

carrot a root and cabbage a leaf vegetable. These vegetables are rich in a variety of nutrients including carotenoids and vitamin C.

A vegetable-rich diet is highly recommended for weight management as it is low in calories. The wide variations in vegetable colour, fragrance, taste and texture add interest and appeal to meals (Fasuyi, 2006; AVDRC, 2010; Keatinge *et al.,* 2011). In the least developing countries, the consumption of vegetables is declining (Rosen & Shapouri, 2008). Access to vegetable rich diets is unaffordable for many of most poor households. A vicious cycle of poverty and malnutrition is prevalent in many South African households, especially those in the rural areas whose incomes fall well below the poverty line (Monde, 2003; Vorster, 2010). As a result micronutrient deficiencies are among the major concerns contributing to child mortality, impaired scholastic ability and low productivity in adults (Jones, 1998; Vorster, 2010**)**. This is particularly sad because vegetables are one of the most readily available sources of many important nutrients

It is estimated that low vegetable and fruit intake contributes to approximately 2.7 million deaths a year from chronic diseases and causes about 31% of ischemic heart diseases and 11% of strokes worldwide (WHO, 2003). The World Health Organisation (WHO) recommends a daily intake of at least 400 g of vegetables and fruit (WHO, 2003). A global analysis on fruit and vegetable availability was conducted by FAO in 2002. The analysis revealed that North America, Europe and Asia are over the critical level of 150 kg per capita per year (400 g per day), with South-America sitting on this level, whilst Africa is far below target level with an average value of 100 kg per capita per year (Ganry, 2009). Low fruit and vegetable intake is ranked as the sixth main risk cause of child mortality in the world (WHO-FAO, 2005). This problem directly impacts on nutritional security, and therefore there is an increasing demand to include nutritional losses as part of comprehensive food data.

Human population is estimated to reach 9 billion in 2050 (UN Population Division/ DESA, 2008) and the high incidence of poverty and malnutrition in developing countries means that more land is required for food production. This situation demands the most efficient use of already produced food supplies (Fehr & Romao, 2001). Duncan (1998) recommended that in order to achieve food security in South Africa, mainstream development strategies which strongly defined anti-poverty objectives must be put in place. This would include the promotion of nutrition education in rural areas to enable individuals to make correct food choices (Duncan, 1998). This approach would require teaching communities how they can put what is already available in their localities to sustainable use. For many developing communities, one good opportunity to achieve this would be to assess and minimise postharvest vegetable losses at all points along the supply chain (Kader, 2005; Kitinoja, 2010).

Growing vegetables helps sustain livelihoods through employment creation thus reducing poverty (AVDRC 2010).Compared to cereal production, horticultural production is regarded as a high value business because it generates higher profits and provides twice the amount of employment opportunities per hectare production (Subramanian *et al.,* 2000; Ali *et al.,* 2002; Joshi *et al.,* 2003; Gabre-Madhin & Hagglade, 2003; Cock & Voss 2004; Minot & Ngigi, 2004; Weinberger *et al.*, 2005). Horticultural producers can generate five to eight times more profits than cereal farmers, depending on the crop (Subramanian *et al.,* 2000). This sector also boosts foreign reserves by creating exports and also generates off-farm employment through value addition activities, such as the canning and packing industries (Weinberger *et al.*, 2005). However, Parallel to this increase in production there is increase in postharvest losses. This situation can be improved by conserving as much produce as possible through the reduction of postharvest losses and waste (Gustavsson *et al.*, 2011).

B. POSTHARVEST LOSSES AND THEIR ORIGIN

Definition of postharvest loss

Various definitions of postharvest food loss have been reported in the literature (Table 2). Any wholesome food commodity, raw or cooked, that is thrown away or is regarded to be of downgrade quality and does not fetch its potential revenue, qualifies as a postharvest loss (Bourne, 1976; Kader, 1983; Fehr & Romao, 2001; Ladaniya 2008; EUC, 2009). Postharvest losses originate from poor pre-harvest and postharvest management including bad handling of produce during transit and storage leading to partial or total loss in produce quality (Prusky, 2011). Food waste which is often referred to in literature as ‘food losses’ and ‘spoilage’ is a major concern with regards to postharvest losses. This type of loss relates to products intended for human consumption occurring at the end of the food supply chain as a result of retail and consumer behaviour (Parfitt *et al.*, 2010). Reasons for food waste can stem from dislike and taste preference. This is a common case in developed countries where consumers are very sensitive to product appearance or cosmetic

Table 2 Various definitions of applied to postharvest loss for different food products

Definition	**Food group**	**Reference**
That weight of wholesome edible product (exclusive of moisture content) that is normally consumed by humans and that has been separated from the medium and site of its immediate growth or production by deliberate human action with the intention of using it for human feeding but which, for any reason, fails to be consumed by humans.	Horticultural crops	Bourne, 1976
These are qualitative and quantitative losses that take place in horticultural produce between harvest and consumption.	Horticultural crops	Kader, 1983
That portion of fruit and vegetables which is produced but does not reach its natural destination: human consumption.	Fruit & Vegetables	Fehr & Romao, 2001
Physical (weight loss and decay), nutritional, cosmetic (loss of appearance as a result of shrinkage), and economic in nature.	Citrus fruits	Ladaniya, 2008
Any food substance, raw or cooked, which is discarded, intended or required to be discarded.	Food Waste	EUC, 2009

quality (Ventour, 2008; Stuart, 2009; FAO, 2011).

Consumers with more disposable income at times purchase more than what they need and as a result waste edible food by simply throwing it away (Gustavsson *et al*., 2011). Vegetables are among the most-wasted food items (Ventour, 2008). It is estimated that of the 19.5 million tonnes of food lost at the retail level for USA in 2008, 12% of this was attributed to fresh vegetables and another 4% to processed vegetables (USDA/ERS, 2010). Furthermore, USA food losses at the consumer level for that same year were approximately 37.7 million tonnes and of this fresh and processed vegetables accounted for 14% and 6% of respectively (USDA/ERS, 2010). The total food wastage (222 million tonnes) in industrialised countries is nearly equivalent to the net production (230 million tonnes) in sub-Saharan Africa (Gustavsson *et al.*, 2011)

Types of postharvest losses

The common categories of postharvest loss are quantitative and qualitative losses in the post harvest system (Ladaniya, 2008). Quantitative loss also referred to as physical loss cause a reduction in product weight (Rahman, 2007; Hodges et al., 2011). A downgrade in quality leads to loss of consumer appeal and is frequently described by comparison with locally accepted standards for premium quality such as appearance, taste, texture and nutritional value (Ladaniya, 2008; Flores, 2000. There is revenue lost from both quantitative and qualitative losses. The cost of postharvest losses cuts across the entire food supply chain and negates on the potential profits of every actor involved in the vegetable handling and marketing system. The economic losses also influence the marketing prices of each commodity. Accordingly, products with higher postharvest losses often fetch higher prices (Kader, 2002; Sudheer & Indira, 2007).

Although the causes of losses may be readily apparent, the complexity and heterogeneity within vegetable marketing systems makes it difficult to quantify postharvest losses. Literature reports on quantitative losses of vegetables as an entity are limited. Reports on vegetables losses are often combined with those of fruits (Kader, 2005; Parffit *et al.*, 2010; FAO, 2011). However, vegetables are very diverse in their morphology and this is an important determinant of postharvest quantitative losses. Leafy vegetables are more perishable than roots and tubers and also easily susceptible to wilting, mechanical injury and decay (Kitinoja, 2010). To obtain reliable data on postharvest vegetables losses requires investigating losses of specific vegetables as opposed to looking at losses of combined food groups. This strategy provides more insight on postharvest vegetable losses regarding their critical control points. Armed with the correct information, policy makers are able to come up with appropriate loss reduction interventions to control the problem.

Qualitative losses are much more difficult to assess than quantitative losses (Kader & Rolle, 2004; Dorais *et al.*, 2001).). Losses in quality are evidenced by a decrease in the market value of the product (De Lucia & Assennato, 1994; Ward & Jeffries, 2000). Any vegetable which is misshaped or has some blemishes may be as tasty and nutritious as one that is perfect in appearance. Sadly such produce is only likely to have a market, only if the price is right (Kader, 1983). For most vegetable trades this may entail making price cuts and produce specials for imperfectly shaped produce including products that have passed their “sell by date”.

The inherent nutritional quality of vegetables is of great importance particularly for all consumers at large. Nutritional value of vegetables defines the presence of those essential substances that are important to support life such as vitamins, phyto-chemicals and proximate composition (Lee & Kader, 2000; Sablani *et al.*, 2006). Changes in fresh produce nutritional quality is not visible but plays an important role in making correct food choices. Nutritive losses are primarily due to improper postharvest handling and prolonged storage (Rusell, 2009). Vitamins are the most labile of all nutrients; their retention declines rapidly for produce that is subjected to adverse handling and storage conditions (Kader, 2002; Javanmardi & Kubota, 2006; Rusell, 2009). Postharvest nutrient losses impact negatively on the nutritional wellbeing of consumers because it is the quality, and not just the quantity of food in a diet that determines the nutritional status of an individual (Vorster, 2010).

There is a dearth of information on the monetary value of postharvest vegetables losses as a food entity. The available data for most countries combine fruit and vegetable losses whilst others report on collective food losses (Kader, 2005; WRAP, 2011; Parfitt *et al.*, 2010; FAO, 2011). A survey conducted in the USA by Kantor *et al.* (1997) revealed that combined fruit and vegetable losses accounted for nearly 20% of the monetary value of food losses at the consumer and food service levels. These losses were due to product deterioration, discarding of excess perishable products and plate waste (food not consumed by the purchaser).

In 2004, Vietnam produce export revenues declined for by US$15 million (R120 million) from the previous year’s returns. Inadequate postharvest technologies were identified as the primary cause of this substantial economic loss (Socialist Republic of Vietnam, 2004). Collective postharvest food losses particularly in the form of waste are reported to cost the USA economy at least US$100 billion (R800 billion) annually (Jones, 2006). Approximately 20% of this loss comprises of fresh fruit and vegetables. In the UK, food waste alone (purchased but not eaten) is valued to be in the region of £10.2 billion (R147 billion) per year (DEFRA, 2007). Raw and minimally processed vegetables are perceived to account at least 9% of the food waste in UK (Parfitt, *et al.*, 2010; FAO, 2011).

Social/Indirect Costs of Postharvest losses

Postharvest losses aggravate hunger by causing less food to be available for consumption (FAO, 2009). In addition, consumers are deprived of getting a premium product for every qualitative loss. When 30% of a harvest is lost, 30% of all the factors that contributed to producing the crop are also wasted (World Resources, 1998). This in turn has serious repercussions on poverty alleviation, income generation and economic growth. Vegetable production is a resource intensive industry and any means of loss translates into resource waste. The world's already limited natural resources are not spared from wastage by the losses.

Agriculture alone utilises almost 80% of all fresh water, making a huge impact on the water footprint (FAO, 2009). Agricultural and industrial growth has seen many countries extracting ground water faster than it can be replenished (Mexico by 20%, China by 25%, India by 56% (Marien, 2011). With an increasing decline of global fresh water resources especially in the arid and semi-arid areas, there is great need for more efforts aimed towards sustainable water use. This highlights the importance of reducing postharvest losses as part of the drive to increase food availability. Promoting resource conservation can serves as a complementary alternative to increasing resource inputs aimed towards increasing agricultural production.

Vegetable production utilises various forms of mechanical energy. This energy is required for ploughing, planting, applying agrochemicals, irrigating, harvesting, refrigeration, transporting, food processing, and packaging of vegetables (Yahia, 2008; FAO, 2009). All these processes consecutively contribute to a number of negative environmental impacts, which impart on, among other things, climate change (Maraseni *et al.*, 2010).

Life cycle assessments of carbon footprint emissions from fresh produce primary production and throughout the product supply chain (transport and refrigeration) have been studied (WRAP, 2011; Gonzàlez *et al.,* 2011). The findings reveal that different carbon gas combinations are produced in all vegetable production sectors and that the total amount of carbon emitted varies for all different vegetable types (Gonzàlez *et al.,* 2011). Advances in food production have given rise to the intensification in mechanisation and modernisation of agriculture processes. Such advances contribute to increased production of green house gas (GHG) emissions. These processes continuously demand more fuel, farm machinery and agrochemicals (Hodges *et al*., 2011; Gustavsson *et al*., 2011). Controlling food waste is one way of monitoring the efficiency of these production practices. It is crucial to monitor and evaluate as to whether the present patterns of production and consumption are appropriate or not. This will entail assessing the magnitude and impacts of postharvest losses and waste

C. CAUSES OF POSTHARVEST LOSSES

The major causes of postharvest losses can be classified into direct primary (technical origin) and indirect secondary (socio economic origin) factors (Kader, 2002, Sudheer & Indira, 2007). Both the primary and secondary factors contribute to physiological deterioration, mechanical damage, biological and microbiological spoilage of fresh produce. Table 3 highlights some of the common causes for postharvest loss in vegetable production and marketing systems.

Primary causes of losses and waste

Primary causes of postharvest vegetable losses are those from which certain mechanical, physiological and environmental factors are directly responsible (Sudheer & Indira, 2007). These causes can complement each other. Damage caused by microorganisms is nearly always preceded by mechanical, chemical and or physical damage, thereby weakening the product's natural defences, and facilitating attacks by fungi, bacteria or moulds. Mechanical damage can arise from careless and rough handling of vegetables during harvesting, packaging, transportation and storage. There are three main mechanisms of mechanical damage, namely vibration, compression, and impact damage. These cause mechani-

Table 3 Classification of postharvest vegetable losses and their major causes (FAO, 1989; Flores 2000; Marsh *et al.*, 2001)

Primary Causes	**Secondary Causes**
Biological	Preharvest management
Microbiological	Harvesting methods and handling
Chemical	Storage type
Biochemical	Transport mode, type and availability
Physiological	Refrigeration facilities
Mechanical	Drying equipment
Environmental	Marketing and processing systems
Pathological	Legal standards in place
Physical	Tool maintenance
	Bumper crops creating over supply.
	Type of packaging

-cal damage in the form of cuts, cracks, punctures, abrasion, scuffing, and scratches with the predominant form being bruising (the darkened area visible under the surface of many vegetables and fruits). Bruising usually detracts from the quality of the produce and can, with time, provide a site for decay to start (Bollen, 2006; Opara, 2007). Mechanically injured vegetable produce is more prone to attack by biological and microbiological spoilage organisms. Presence of mechanical injuries increases rate of water loss and respiration activity in vegetables, leading to rapid quality loss. Processing operations such as spillage, abrasion, excessive polishing, peeling and trimming can also add to loss of commodity (Hodges *et al*., 2011).Physiological deterioration of vegetables refers to aging of products during storage due to natural reactions (Flores, 2000).

It may be subdivided into the normal and the abnormal. The former covers respiratory losses that take place in all living materials; the decline in vitamin content and transpiratory or wilting losses of water. Abnormal physiological losses arise for example from exposure to extremes of heat or cold or otherwise unsuitable environmental conditions (Barbosa-Cánovas *et al.*, 2003). Examples include freezing injury, chilling injury, and sunburn (Kader, 1983) which causes a yellow or bronze discolouration when fruit surface temperatures reach 46 – 49°C in the presence of direct light (Wand *et al.,* 2005).Certain changes that occur during ripening, senescence, including wilting, and termination of dormancy (e.g. sprouting) may increase the susceptibility of the produce to mechanical damage or infection by pathogens (Nunes, 2008; Babita & Kiranmayi, 2010).

Pathological losses of vegetables are caused by microbial spoilage organisms such as fungi, bacteria, yeasts and moulds. Common rot causing pathogens in vegetables include fungal strains such as *Alternaria, Botrytis, Diplodia, Rhizopus, Pencillium* and *Fusarium,* and among bacteria *Erwini*a and *Pseudomonas* cause extensive damage (Sudheer & Indira, 2007). Vegetables are prone to disease attack by these organisms because of their succulent nature. Postharvest diseases can cause extensive commodity breakdown, sometimes spoiling the entire package. At least 36% of vegetable decay is caused by soft rot bacteria, with the source of infection coming from the field; surface cleaning water, contact equipment and storage environment (Kader, 2002; Sudheer & Indira, 2007).

Postharvest environmental conditions play a very important in the shelf life quality of vegetables. Such environmental factors include temperature, humidity, proportion and composition of gases in controlled atmospheric storage. Temperature is the most important factor that influences deterioration of freshly harvested produce (Ladaniya, 2008). The rate of fresh produce deterioration increases by 2-3 folds with for every 10°C increase in temperature, (Kader, 2002).Temperature also determines spore germination and growth of pathogens. Optimum storage temperature varies from one commodity to the other.

Relative humidity (RH) effects on vegetable inherent quality are interrelated with the storage temperature. High temperature and relative humidity favour growth of microorganisms which cause extensive damage to the produce. Humid tropical climate conditions favours decay of bruised yam tubers and also encourages the proliferation of harmful organisms. Excess moisture promotes the growth of fungi and other spoilage micro-organisms. This increases susceptibility of improved varieties of produce to moulds and insect pests (Akinbode, 1983; Perez et al., 2003; Nunes, 2008).

Other principal biological and microbiological agents causing the direct disappearance of food from consumption are rodents, insects, bacteria, moulds, other larger animals. Stacked vegetables in boxes, crates, baskets or trucks after harvest may be subject to cross contamination by other spoiled vegetables within the container (Barbosa-Cánovas *et al.*, 2003). Postharvest losses of vegetables can also be as result of contamination by noxious substances including pesticides during handling. Chemical deterioration caused by chemical or biochemical agents can lead to significant losses in nutritional value and production of undesirable components e.g. rancidity in fats and oils and Maillard reactions of sugars (Kader, 2002).

Secondary causes of losses and waste

Vegetable loss is most prevalent when there is unavailability of essential tools and equipment coupled with poor maintenance and unavailability of spare parts (Kader, 1983). Inadequate infrastructure and advanced production techniques remain major obstacles contributing to food losses for many developing countries (Parfitt *et al.*, 2010). This can be evidenced by the huge variation in magnitude of postharvest losses observed from farm to retail for developed and developing countries respectively. Losses in USA range between 2 – 23% whilst losses exceed 50% in the less technically advanced countries (Kader, 2002). Lack of packing houses in India is a major postharvest challenge, with vegetables and fruits being generally packed in the field and some even transported without transit packaging (Reardon *et al.*, 2007).

Mittal, (2007) highlights that at least 30% of India's vegetable and fruit produce is wasted primarily from lack of cold chain facilities.

The harvesting method (hand vs. mechanical) and general handling of crops after harvesting is very important. Use of inappropriate harvesting tools facilitates mechanical injuries which in turn accelerate loss of water and vitamin C (Opara, 2007; Arazuri *et al*., 2010). Furthermore delays between harvesting and cooling promote water, flavour and nutritional value loss as well as decay (Kader, 2002). Capital funding, educational facilities, administrative and managerial skills are requisites for satisfactory fresh produce handling (Hodges *et al*., 2011; Kitinoja, 2010). High postharvest losses can be as a result of ignorance in scientific and technological techniques associated with the conservation of food products. Poorly maintained packing cold stores, with limited space and shortage of qualified trained personnel to conduct timely repairs, also impact negatively on the quality of fresh produce. Surplus produce due to lack of market availability coupled with change in destination of produce, creates prolonged storage thus increasing susceptibility of produce spoilage (Tadesse, 1991; Hodges *et al*., 2011).

Enormous losses can be incurred when there is inadequate transportation to move fresh produce to the food market before it spoils (Caixeta-Filho, 1999). Delicate, sensitive produce is often thoughtlessly, roughly handled during transporting, and the damage caused greatly enhances further deterioration from physiological and pathological causes (Yahia, 2008). Other factors include use of ordinary open and non-refrigerated trucks, poorly ventilated, on very rough and poorly maintained roads. Shortage of chartered planes and cancellation of regularly scheduled flights are major causes of postharvest losses of export crops contributing to rapid deterioration of produce at destination (Tadesse, 1991).

Social and cultural factors such as urbanisation, education and population growth and its characteristics can influence the quantity and quality of produce available. Traditional processing and marketing systems can be responsible for high losses (Parfitt *et al.*, 2010). Poor sanitation facilities and in wholesales including overcrowding, and lack of adequate facilities for loading and unloading of produce can indirectly contribute to serious fresh produce losses too. Fresh vegetable losses can also be a direct result of human psychology whereby a fresh commodity is not eaten and is thrown away because the end user did not fancy eating it or for religious taboos (Parfitt *et al.,* 2010).

The kind of policies in place also has an indirect impact on postharvest loss management. Governmental regulations and legislations regarding price controls can be counter-productive as they encourage fraud and provide no incentive for producing high quality produce or for postharvest quality maintenance (NAS 1978; Kader, 2003). These legal standards can affect the retention or rejection of food for human use by being too lax or unduly strict (Marsh *et al.,* 2001). For instance, contractual penalties, product take back clauses and poor demand forecasting had a combined influence that led to 10% over-production and high levels of food wastage in the UK food supply chain (Ventour, 2008). Farmers in the UK experience a lot of gross vegetable waste (Stuart 2009). In one case study, truck loads of good carrot produce had to be ploughed back into the ground because the produce did not meet the regulated cosmetic standards (Stuart, 2009). Often farmers are also restricted to sell their produce to other retail firms as part of the contractual requirements. As a result the farmer has no choice but to divert all surplus vegetable produce the human food supply chain to usage for livestock feeds and manure (Stuart, 2009).

D. MAGNITUDE OF POSTHARVEST LOSSES

Combined data of postharvest losses of fruit and vegetables

Postharvest vegetable loss is a global problem, affecting both developed and developing countries. Early global reports on postharvest losses that include vegetables are based on combined fruit and vegetable loss estimates made by the National Academy of Sciences (NAS, 1978). The magnitude of fruit and vegetable losses were reported to be higher at the production sites compared to the consumption end for developing countries while the opposite was observed for the developed countries (NAS, 1978). Estimates made from this study (Table 4), also revealed that the overall magnitude of fresh produce losses for both developing and developed countries were equal (32%) representing a global loss of at least one third of all harvested produce (NAS, 1978).

More recently postharvest losses in developing countries have been estimated to be still higher at the production level as compared to developed nations (Kader, 2005; Prusky, 2011). Some of the causes include low levels of postharvest technology, few trained personnel, and huge variances in standard compliance, unreliable power supply, lack of proper maintenance, inefficient utilisation of cold storage and refrigerated transport facilities (Kader, 2005). Data on postharvest loss

Table 4 Estimated postharvest global losses (%) of fresh produce (NAS, 1978)

Locations	**Developed countries**		**Developing Countries**	
	Range	Mean	Range	Mean
From production to retail sites	2 – 23	12	5 – 50	22
At retail, food services and consumer sites	5 – 30	20	2 -20	10
Cumulative total		32		32

estimates is location and season specific (Kader, 2005). This makes it difficult for researchers to estimate the losses by extrapolating from even a specific, well characterised loss situation. As a result most experts tend to cite indicative figures of minimum overall quantitative losses for planning purposes. Some the figures commonly cited are 10% for cereal grains and grain legumes, 20% for roots and tubers and 30% for fruits and vegetables (FAO, 2009).

There are challenges in accurately comparing the regional reports data on postharvest fresh produce losses (Table 5). Some of the information dates as far back as 20 years ago. Most of these data are also based on percentage guess estimates which do not provide concrete information on the actual magnitude of the losses (Tadese, 1991; Masanganise, 1994; Kantor *et al.*, 1997). The abundant current reports are also predominately limited to Asian countries, (Wang & Bagshaw, 2001; Feng, 2001; Rolle, 2006; Weinberger *et al.*, 2008; Genova *et al.*, 2006; Sarawathy *et al.*, 2010).Losses in Asia range from 3 – 50% (Feng, 2001, Opara, 2003; Rolle, 2006).

India, China and Japan are among the top global vegetable producers and have been reported to experience substantial postharvest losses annually. Losses in India alone are even believed to be sufficient to meet UK's annual fresh produce needs (Reddy, 2000). Expert estimates of fruit and vegetable losses In Africa place the volume of loss to be around 20 – 45% whilst actual sampling methods show a lower range of 10 – 21% (Table 5). Additionally there is limited data available on postharvest losses for America and Europe. The data available for America (23 – 25%) was obtained in 1997 (Kantor *et al.*, 1997) and this limits researchers to continue to base their judgement using these exact values Kader, 2005; Parfitt *et al.*, 2010).

A study conducted in the UK by Garnett, (2006) estimates postharvest fruit and vegetable losses in UK to be around 25% with the highest losses occurring at the supermarket level due to 'quality out grades' of produce that does not meet certain cosmetic standards (Stuart, 2009). Interestingly the global fruit and vegetable postharvest loss reports indicate that despite the variances in technical advancement both industrialised and developing countries dispose of roughly similar quantities of food with at least one third of all produce still being lost (Kader, 2005; FAO, 2011; Prusky, 2011) as was observed in earlier studies by NAS (1978). According to a recent FAO-commissioned study, approximately 1.3 billion tonnes of food produced for human consumption is lost annually (Prusky, 2011). It therefore follows that for

Table 5 Regional postharvest losses of fruit and vegetables

Region	Country	Loss (%)	Method	Reference
Africa	Ethiopia	25 – 35	Estimate	Tadesse, 1991
	Zimbabwe	35 – 45	Estimate	Masanganise, 1994
	Nigeria	20 – 30	Estimate	Aworh, 2010
	Benin	14 -18	Sampling	Kitinoja, 2010
	Ghana	13 -17		
	Rwanda	10 – 21		
	Mean	**20 – 28**		
Asia	China	15 – 35	Interviews	Feng, 2001
	Oman	3 – 19	Survey	Opara, 2003
	Indonesia	20 – 50	Estimate	Rolle, 2006
	Iran	>35		
	Korea	20 – 50		
	Philippines	27 – 42		
	Sri Lanka	16 – 41		
	Thailand	17 – 35		
	Vietnam	20 – 25		
	China	20 – 25	Estimate	Paliyath *et al.*, 2008
	India	25 – 40	Estimate	Sarawathy *et al.*, 2010
	Mean	**20 – 36**		
Europe	UK	25	Estimate	Garnett, 2006
	UK 'retail out grades'	25 – 40	Estimate	Stuart, 2009
	Mean	**25 – 33**		
Americas	USA	23 – 25	Estimate	Kantor *et al.*, 1997
	Brazil	20	Interviews	Fehr & Romao, 2001
	Mean	**22 – 23**		
Global		33	Estimate	NAS, 1978; Kader, 2005
		28 – 42	Estimate	Zaldivar, 1991
	Mean	**31 – 38**		

every percentage increase in fresh production there has been a parallel increase in postharvest losses. This actually defeats the purpose increased production if it means that there is also going to be increased food wastage.

Postharvest losses and waste of vegetables

Postharvest data on collective fruit and vegetable losses is informative. However, it does not show exactly how vegetable losses are occurring on the ground. A detailed look at postharvest losses for vegetables as a separate food group is therefore more meaningful. Postharvest vegetable losses may differ significantly from general collective fruit and vegetable losses. Table 6 provides examples of case studies conducted in Philippines and Japan where the vegetable losses were differed from collective food group losses. This is an example of why it is important to separate vegetable losses from those of other food groups (Kitinoja, 2010). Therefore losses for individual vegetable types should be equally considered.

Postharvest losses of different types of vegetables

Researchers have a tendency to generalise vegetable losses. The use of combined vegetables can be misleading or inaccurate (FFTC, 1993; Rolle, 2006). Table 7 for example presents the differences in magnitude of postharvest losses between specific vegetable commodities. Leafy vegetables are more susceptible to wilting through moisture loss and tomatoes are prone to mechanical injuries whilst tubers like potatoes can last longer if kept in dry and optimum temperature conditions. From the data presented, average losses for tomato and cabbage are comparable at 28% and 29% respectively. However a closer look at the reported loss ranges reveals that losses for cabbage can reach 62% while losses in tomato are at most 35% (Feng, 2001, Zheng, 2001; Pal *et al.*, 2002, Udas *et al.*, 2005).

Root vegetables such as onions and potatoes are regarded to be more shelf stable with comparatively lower postharvest loss volumes (11 – 16%) than leafy and other tender vegetables (Zheng *et al.*, 2001; Zulifiqar *et al.*, 2005; Kumar *et al.*, 2006). Vegetable losses are also location specific. Postharvest losses for potatoes for example on average range from 15 – 17% in other areas (Table 7) ,but for Bangladesh the losses are higher ranging from 23 – 28% (Zulifiqar *et al.*, 2005; Kumar *et al.*, 2006; Hossain & Miah 2009). To further investigate the losses the exact

Table 6 Postharvest vegetable loss alone compared with combined fruit and vegetable Loss (FFTC, 1993; Rolle, 2006)

Country	**Loss per group (%)**	
	Fruit & vegetables	**Vegetables**
India	40	17
Japan	10	10 – 30
Korea	20 – 50	26
Philippines	40	42

Table 7 Postharvest losses of specific vegetables by country

Produce	**% Loss**	**Country**	**Reference**
Cabbage	23 - 62	China	Feng, 2001
	10- 15	China	Zheng, 2001
	25 - 30	India	Pal *et al.*, 2002
	43	Nepal	Udas, *et al.*, 2005
	15 - 20	India	Gajbhiye *et al.*, 2008
Range **(Mean)**	23 – 34 **(29)**		
Tomato	30	Brazil	Vilela *et al.*, 2003
	20	Ghana	Bani *et al.*, 2006
	20	Pakistan	Rehman *et al.*, 2007
	35	India	Gajbhiye *et al.*, 2008
Range **(Mean)**	20 – 35 **(28)**		
Cauliflower	29 -35	India	Pal *et al.*, 2002
	47	Nepal	Udas *et al.*, 2005
	15 - 20	India	Gajbhiye *et al.*, 2008
Range **(Mean)**	30 – 34 **(32)**		
Onion	10 - 12	China	Zheng *et al.*, 2001
	9	Pakistan	Zulifiqar *et al.*, 2005
	12.9	India	Kumar *et al.*, 2006
Range **(Mean)**	10 – 11 **(11)**		
Potato	12	Pakistan	Zulifiqar *et al.*, 2005
	10.5	India	Kumar *et al.*, 2006
	23 - 28	Bangladesh	Hossain & Miah, 2009
Range **(Mean)**	15 - 17 **(16)**		

location of the location must be identified. This in turn also reveals how the losses impact on the different individuals directly involved in the different vegetable the supply chains (Weinberger *et al.*, 2008; Hodges *et al*., 2011).

Postharvest losses of vegetables along the supply chain

The magnitude of loss experienced by each chain actor along the supply chain is different. Depending on the location, losses for any vegetable commodity such as is the case for cabbage, cauliflower and tomato (Table 8), can be twice or thrice that observed at either end of the supply chain (Udas *et al*., 2005; Directorate of Research, 2005). Table 8 shows how losses along the supply chain mostly affect the farmer and retailer compared to the middleman.

There is limited data on combined economic and physical loss values along the supply chain but using the limited data available (Table 8) it can be seen that retailers are the most affected financially. Losses at the retail stage are more expensive and have greater environmental impact because of the all the value addition costs for packaging, transport and storage accrued along the chain (Buzby, *et al*., 2009). Retailers are often faced with the challenge of implementing an increase in price mark ups for fresh produce as they too need to generate reasonable profit to sustain their operating systems from whatever volumes remain after factoring in the losses. In the end not many people will be able to have access to a vegetable rich diet simply because of the cost (Hodges *et al*., 2011; Parfitt *et al.,* 2010; Vorster, 2010).

Table 8 also shows that not all vegetable supply chains are similar with some being more complex than others. Most supply chains from Asia have a collector in their distribution chain, others only have three major actors as is the case for the studies conducted in Africa, while industrialised countries not included here have even more complex chains with more actors being involved in the handling prior to reaching the retailer (Buzby, 2009; FAO, 2011). Therefore, it is difficult to accurately compare the actual share of both physical and economic losses experienced by individuals from different supply chain data. Computing the average losses provided in Table 8, it appears that the farmer and retailer both lose around 10% of the produce. This might actually be a misconception because the number of supply chain actors is not the same for each chain and it might be possible that for Africa it is also the farmers who bear the losses for collectors found in Asian distribution chains.

Table 8 Types of vegetables, showing losses at along the supply chain

Vegetable	Loss				
	Farmer	**Collector**	**Wholesaler**	**Retailer**	**Location**
Cabbage	9.0	-	-	3.4	Nepal[2]
	20.1	-	6.5	28.1	Ghana[5]
Cauliflower	9	-	-	34	Nepal[2]
	10.25	-	1.75	3.75	Assam[1]
Eggplant	23.1	-	13.1	5.0	Tanzania[4]
	13.9	-	11.3	16.2	Ghana[5]
Pepper	5.9	-	6.2	11.0	Benin[5]
Tomato	8 (10)	4 (6.3)	4 (8.7)	3 (9.4)	Vietnam[3.1]
	2 (7.9)	1 (3.7)	7 (30.8)	7 (41.8)	Lao PDR[3.2]
	10 (13.7)	2 (3.7)	7 (17.1)	6 (22.1)	Cambodia[3.3]
	3	-	-	7	Nepal[2]
	25.1	-	21.5	23.0	Ghana[5]
	23	-	31.2	26.4	Benin[5]
	7.8	-	10.7	14.7	Rwanda[5]
	8.7	-	15.1	16.4	India[5]
Yardlong bean	8 (26.7)	1 (3.6)	1 (3.6)	3 (14.6)	Lao PDR[3.2]
	8 (13.7)	3 (9.1)	5 (11.5)	6 (23.5)	Cambodia[3.3]
Cucumber	2 (2.0)	1 (0.8)	1 (0.6)	6 (9.4)	Lao PDR[3.2]
	6 (4.6)	4 (5.4)	5 (8.6)	4 (9.8)	Cambodia[3.3]
Chilli	8 (9.2)	5 (11.5)	2 (7.4)	3 (27.1)	Vietnam[3.1]
	5 (27.9)	1 (13.5)	1 (3.1)	4 (43.7)	Lao PDR[3.2]
Chinese Kale	4 (8.9)	3 (9.6)	4 (16.30	5 (24.4)	Cambodia[3.3]
Mean	**10**	**2.8**	**8.1**	**10.7**	

[1]Directorate of Research (Agric) (2005).
[2]Udas *et al.*, 2005
[3]Genova *et al.*, 2006abc
[4]Barry *et al.*, 2009
[5]Kitinoja, 2010

The mapping losses of specific vegetable types along any supply chain provides a more holistic approach for locating postharvest losses and assists in the causes and potential control measures (Weinberger *et al.*, 2008). Mapping of losses across similar supply chains with similar chain actors helps to identify and determine the extent to which the different individual actors involved are affected by the losses. Weinberger *et al.* (2008) was able to show how the volume and value of postharvest losses varies across the supply chains actors for three Asian countries with similar supply chains (Table 9). They revealed that with regards to total volume of physical losses experienced along the distribution chain it is the farmer who is most affected (41%) while the retailer experiences the highest share of economic loss of almost 38% (Fig. 1). Therefore while losses at the collection and wholesale centres are important, it is at the start and end sections of the chain where the issue of postharvest vegetable losses is more critical for this particular case study. It is clear that mapping of losses if carefully conducted has the potential to provide informed and reliable data making it possible to identify and pinpoint control areas so as to curb the losses effectively (Genova et al., 2006; Weinberger et al., 2008; WRAP, 2011; Kitinoja, 2010).

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E. METHODS FOR ASSESSING POSTHARVEST LOSSES

Three methods have been used to evaluate the magnitude of postharvest losses of vegetables, namely; (a) professional estimates (often referred to a guesstimates), (b) interviews of individual key individuals involved at different stages in the vegetable supply chain using structured questionnaire, and (c) sampling of produce for postharvest quality evaluation at various points along the supply chain (Blond, 1984; Tadese, 1991; Weinberger *et al.*, 2008; Kitinoja 2010). Reports on general estimates by the authors who at times would be referring to loss estimates or measurements published by other authors are the most predominant (Kitinoja 2010).

Expert estimates on postharvest losses and waste create awareness by providing a rough indication of the severity of the problem, and can be generated from secondary or historical data sources such as local municipal records, newspaper articles and or government statistic publications (Fehr & Romao 2001; Piadozo *et al.*, 2007). Generating estimates is cost effective and very often not time consuming. However, the process of interpretation of the data strongly depends on the expert knowledge, experience and judgement of the observer and at best, can be

Table 9 Combined Vegetable losses along the supply chain (Genova *et al.*, 2006abc; Weinberger *et al.*, 2008)

Vegetable	Loss*				
	Farmer	Collector	Wholesaler	Retailer	Location
Physical loss	8	4.5	3	3	Vietnam
	7	3	5.3	5.3	Lao PDR
	4.3	1	2.5	5	Cambodia
Mean (share)**	**6.4** (37)	**2.8** (16)	**3.6** (21)	**4.4** (26)	
Economic	9.8	7.6	8.3	15.5	Vietnam
(US$/MT)	19.3	7.0	9.2	28.7	Lao PDR
	10.1	7.2	14.1	19.8	Cambodia
Mean (share)**	**13.1** (25)	**7.3** (14)	**10.4** (20)	**21.3** (41)	

*Average values for vegetables losses given by Genova *et al.*, a, b, c, 2006 from Table 6
** Percentage share of the total postharvest losses by each supply chain actor

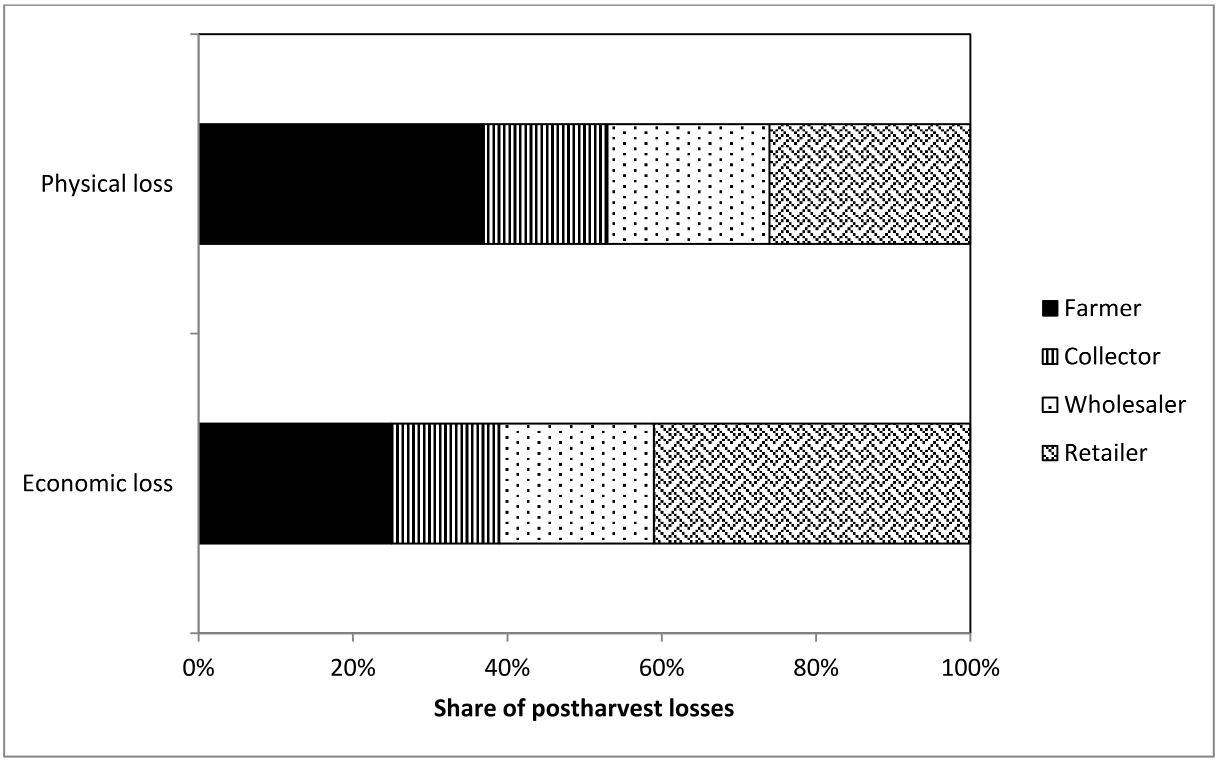

Figure 1 Distribution of percentage share of postharvest losses of vegetables along the supply chain (Adapted from Weinberger *et al.*, 2008).

mere guesstimates. The reliability of estimated loss data is questionable since the figures may differ considerably depending of the season and supply chain. In some cases there is the temptation to cite “worst case” figures which exaggerates the problem (Kitinoja, 2010).

Field based surveys on produce losses focusing on specific links in the supply can also be done. Conducting surveys can involve direct observation of handling practices, interviewing key individuals regarding their standard postharvest practices and at times sampling of vegetable consignments for quality evaluation (Genova *et al.*, 2006abc; Weinberger *et al.*, 2008). The survey technique attempts to understand the postharvest losses within the context of the whole system of production, handling, and marketing of the commodity in question. Loss assessment manuals have been published by the United Nations Food and Agriculture Organisation (FAO) that are focused on measuring physical losses (changes in weight) and losses in value (changes in quality or decrease in market price per unit) of specific products.

Some surveys are conducted wholly on questionnaires but when actual sampling of the produce is involved at controlled points the data generated are more meaningful and reliable (FAO, 2011). Barry *et al.* (2009) estimated postharvest losses in African indigenous vegetables in Tanzania using semi-structured questionnaires. This approach enabled the authors to identify possible postharvest loss reduction points along the supply chain but their study could not generate specific quantitative losses. The Postharvest Systems Research (PSR) approach is one example of a survey based loss assessment method (Shrewfelt & Prussia, 1993). This method entails tagging and tracing of a specific produce consignment from harvest through packing, storage, and transport to the processing facility or distribution centre all the while measuring changes in quantity and quality attributes. Successful research studies in horticulture using PSR have been conducted at the University of Georgia n the USA (Kader, 2002). Implementation of PSR is however costly and time consuming. The process requires long term use of a vehicle equipped with scientific instruments for quality assessment and sleeping accommodation for the researcher(s) for them to be able to follow through all the steps of postharvest handling that may take days or weeks to complete.

The Commodity Systems Assessment Methodology (CSAM) is another systems approach for quantifying the magnitude of losses and waste (La Gra, 1990). This is a practical-team based method used in fieldwork worldwide. The approach relies mainly on direct observation and semi-structured interviews. The CSAM focuses on face to face information gathering and lies within the capability of common extension services and is also relatively low in cost. Commodity assessments can help identify who (i.e. men, women, growers, traders, retailers) needs what kind of postharvest information to solve the problem (Kader, 2002). Recommendations on corrective action will also be specific to the particular needs of the local community system understudy.

Systems approach methods can be universally applied and they provide more reliable information that is representative of the actual losses occurring directly on the ground (La Gra, 1990). They also provide insight on the perspectives and constraints being faced by the individual chain actors of the whole handling system. They do however require trained technical experts. Some respondents may be unwilling to participate in the survey or provide misleading replies by telling the extension workers ideal answers rather than their actual practice. Most importantly the methods rely on specific case studies of which the data recorded are only specific to that particular point in time (Bagshaw, 2001; Kader, 2002).

The use of surveys aimed at the mapping of postharvest losses along the supply chain in place of generalised estimates provides more reliable information on the inter-relationships between supply chain partners and reasons behind their current practices. Studies on postharvest vegetable losses are still very few and many are not carried using universally-accepted methods such as PSR, CSAM (Yahia, 2008). The little data available are largely limited to field surveys that are not carried out by described methodology or actual field sampling and are therefore difficult to interpret. Hence, although there are huge variations in the magnitude of postharvest losses of vegetables depending on the type of produce, stage along the supply chain and location, it is the method of assessment used that is the most critical and must be strictly monitored as it is crucial towards addressing the problem. There is a need for the development and validation of appropriate postharvest loss assessment methods, so as to scale the level of vegetable losses in relation to global malnutrition (Eboh, 2009; Parfitt *et al.,* 2010). Without reliable data such information may lead to misinformed policy and interventions (Kader, 2005).

F. CONCLUSSION

Postharvest losses are a global problem, and despite the advances made to improve production volumes at least 33% of all agricultural produce never reaches the consumers (Gustavsson *et al*., 2011). Regional data on combined fruit and vegetable losses show that all regions across the globe lose at least 20% of their fresh produce to postharvest losses with extreme losses of 45 – 50% being reported in Africa and Asia respectively. A variety of factors contribute to postharvest losses, the importance of which differs from commodity to commodity, from season to season, and to the enormous variety of conditions under which commodities are grown, harvested, stored, processed and marketed (Hodges *et al*., 2011; Parffit *et al*., 2010). Accordingly, leafy vegetables experience higher losses (28 – 32%) as compared to bulbs and tubers (11 – 16%), hence the losses must be considered separately.

The goal of food and nutrition security cannot be achieved by increasing production without parallel efforts to prevent postharvest losses across food supply chains. Studies conducted reveal that postharvest fresh produce losses are concentrated beyond the farm gate in developed countries but before the farm gate in developing countries (Kader, 2005; Hodges *et al*., 2011). Generally, data on postharvest loss information are scarce, and for developing countries the figures available are mostly guesstimates derived from questionnaires rather than actual measurements from sampling surveys (Hodges *et al*., 2011). Loss data for developed countries such as the UK, Sweden and USA rely heavily on research into general food waste and these studies are mainly centred at the retail and consumer levels only (Buzby, 2009; WRAP, 2011; Gustavsson *et al*., 2011).

To address the problem of postharvest losses, it is important to generate accurate data. The information cannot be generalised from other locations as the losses are reflective of the time and situation they are taken, and these vary with differences in time and the prevailing conditions in each place (Kader, 2005). Further studies are therefore needed to quantify the cost-benefits and wider economic impacts of technological interventions to reduce postharvest vegetable losses.Direct sampling from the supply chain in order to quantify physical and qualitative losses can create awareness on the importance of postharvest crop management (Kitinoja, 2010, WRAP, 2011). Conservation of nutritional content in fresh produce during postharvest handling and storage ensures the quality of the commodity. Sampling can also be done to carry out laboratory trials to assess the response of vegetables under different handling and storage conditions (Javamardi & Kubota, 2006; Nunes, 2008; Babita & Kiranmayi, 2010). Conducting laboratory simulations directly identifies sources of deterioration quickly and provides corrective measures (Bollen, 2006).

There are limited data regarding vegetable losses for many developing countries South Africa included. Given the importance of a varied nutritional diet and the challenges remaining to see food and nutritional security become a reality for many, it is important that more studies on postharvest vegetable losses be conducted to create an awareness of the problem. The impacts of postharvest losses can be quantified on basis of volume of produce lost, changes in produce cosmetic and nutritional quality, the economic value of the loss and these can be traced backwards to estimate the amount of resources (water, energy, fertilisers and labour) wasted. Furthermore, there are growing concerns of climate change and, this calls for the minimisation for green house gas emissions. Postharvest losses contribute to unwarranted emissions (WRAP, 2011). There is need to know how much is being lost first in order to visualise the impact of the problem and come up with effective control measures.

Conducting loss surveys across whole food supply chains ideally gives the best informative results however the process is very costly and researchers are often limited to investigating losses at specific locations only. The farm and retail end of the chains are usually the most affected with regards to both volume and economic value of fresh produce lost compared to all the other key individuals involved, although the magnitude of loss may vary depending on the location. Therefore, postharvest loss surveys focused on the farm gate provide information on how much of the harvested produce leaves the field in a good state while losses at retail reveal just how much of the produce that reaches the market actually gets to the consumer. This study will focus on investigating vegetable losses at retail level in Stellenbosch, South Africa. To do this the physical quantities being lost and the changes in nutritional quality of vegetables after purchasing will be evaluated. The values obtained herein will be used to estimate the losses at the national retail level as well as the environmental impacts of the losses.

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Chapter 3

POSTHARVEST LOSSES AND CHANGES IN QUALITY AND NUTRITIONAL VALUE OF TOMATOES FROM RETAIL TO CONSUMER

Summary

Postharvest losses of tomatoes ranged from 12.50 – 18.16% at retail purchasing. Based on these losses, approximately R1.53 is lost for every kg of tomatoes that is purchased. Decay (11.12 – 52.55%) and mechanical injury (47.45 – 88.88%) were the major causes for loss. After 3 days of post retail storage the tomato losses were 18.52% and 34.34% for cold (10 – 12 ºC) and ambient (22 - 25ºC) storage. Changes in produce quality (weight loss, colour, firmness, ascorbic acid, carotenoids, total soluble solids, acidity and proximate composition) were also evaluated. At low temperature storage weight loss was 0.70 – 1.84%, firmness declined by 15.63 – 23.37% and ascorbic acid declined by 10.65 – 15.46%. Tomatoes kept in the ambient storage experienced a weight loss of 3.41 – 7.06%, firmness decline of 33.61 – 44.20% and ascorbic acid loss of 33.61 – 44.20%. Tomatoes continued to ripen during storage and this was characterised by an increase in red colour change (ΔE) of 5.88 and 6.10 for cold and ambient storage, respectively. Total carotenoids increased by at least 38% and 200% for cold and ambient storage temperature, respectively. At national retail level, the estimated magnitude of the tomato losses were equated to the wastage of 37 200 t valued at R61.64 million. To produce this tonnage, roughly 111.63 million MJ of energy and 4.35 million m^3 of fresh water would have been required. The water waste e could possibly sustain at least 238 356 people per day for a whole year. Furthermore, the estimated losses also contribute to approximately 13.77 million tonnes of unwarranted CO_{2eq} to the environment.

Introduction

The tomato (*Lycoperisicon esculentum*) is one of the most commonly grown vegetables in the world accounting for at least 14% (881 million tonnes) of the world vegetable production (Baas, 2006). In 2010 the total global production of tomatoes was just over 150 million tonnes (DAFF, 2011). Tomatoes account for at least 20% of

South Africa's national vegetable produce after the (41%) potato (DAFF, 2011). This is less than 1 % of the total global tomato production (DAFF, 2011).

Tomatoes are consumed for their flavour and antioxidant properties either raw or processed. The main antioxidants in tomatoes are carotenoids and ascorbic acid which have a protective effect against cancer and cardiovascular related diseases (Rao & Agarwal 2000; Barber & Barber, 2002). At least 85% of dietary lycopene, an important caratenoid is obtained from tomatoes (Clinton, 1998). This lycopene is responsible for the red colour in tomatoes (Brandt *et al.*, 2006). Tomatoes that have reached a fully ripe stage exhibit the highest level of carotenoids, total soluble sugar and ascorbic acid content (Opara *et al.*, 2010).

The quality of tomatoes is characterised on the basis of external (visual appearance; colour, shape, size, absence of physiological disorders and decay) and internal attributes (chemical attributes; sugars, acidity, ascorbic acid and caratenoids), respectively (Zind, 1989; Kader, 2002). Both the external and internal quality of the vegetables are equally important to the consumer whose overall satisfaction with the cosmetic appearance, taste and perceived nutritional benefits will determine a repeat purchase (Kader, 2002; Toor & Savage, 2006; Nunes *et al.*, 2009). Postharvest keeping quality of tomatoes is determined by several factors which include storage, maturity index, temperature and relative humidity (Palop *et al.*, 2010). High temperatures elevate ripening, leading to rapid quality deterioration. Low temperature can retard the rate of metabolic activity and softening of the tomatoes, hence extending shelf life (Kader, 2002). However, storage of tomatoes at low but non-freezing temperatures in the range of 0 - 10˚C can subject the tomatoes to chilling injury (Kader, 2002).

Tomatoes that do not meet the required quality standards are either sold as downgrade (qualitative loss) or have to be discarded (quantitative loss). Postharvest losses of tomato produce can occur at all stages throughout the marketing and distribution chain (Weinberger et al., 2008; Kitinoja, 2010). However, they tend to be greatest at retail level (Weinberger et al., 2008). This is because by the time the fresh produce reaches the retail display, it will be nearing the end of its marketable life. Some of the major challenges facing the vegetable industry include the increasing demand by consumers for safe, nutritious, and "cosmetically perfect" produce (Parfitt *et al.*, 2010). This has contributed to significant postharvest losses through the process of out- grading especially at the retail level (Dorais *et al.*, 2001; Masarirambi *et al.*, 2009; Parfitt *et al.*, 2010).

The supermarket industry holds the largest share of the retail market compared to other small traders (hawkers, vendors and tuck shops) (van Wijk *et al.*, 2006). In South Africa, and indeed globally, the importance of supermarkets as major sources of food purchases continues to increase (van Wijk *et al.*, 2006). Postharvest losses of vegetables in general have been reported to range from 7 – 26% at the retail level (Directorate of Research (Agric), 2005; Udas *et al.*, 2005; Weinberger *et al.*, 2008; Kodjogbe, 2010). The economic losses at the retail level have been reported to account for at least 40% of the total revenue lost across the postharvest supply chain (Weinberger *et al.*, 2008). This means that nearly half of the cumulative postharvest revenue losses from the onset of harvest to retail display are carried by the retailers.

Vegetable consumption in developing countries is relatively low compared to developed nations. The consumption of tomatoes per capita is 12 kg per annum in South Africa, which is less than half that for Europe at 32 kg per capita (DAFF, 2011). Reducing postharvest losses will increase vegetable availability and perhaps affordability due to lower prices. Currently there is no information on the magnitude of postharvest losses of tomatoes between harvest and consumption in South Africa. In the absence of reliable and objective estimates of postharvest losses at any stage, the ways to evolve correct policies, for minimising losses become insurmountable (Kumar *et al.*, 2006).

The present patterns of all food production and consumption should be sustainable with regards to the efficient resource usage and safety of the environment (Maraseni *et al.*, 2010; WRAP, 2011). Given the importance of vegetables in attaining the Millennium Development Goals (MDGs) there is an urgent need to monitor the incidence of postharvest losses. To do this comprehensive food data analysis of the prevailing postharvest vegetable losses must be determined. The causes as well as the economic, environmental and resource impacts of the losses will provide an insight on the severity of the problem. Promoting the reduction of postharvest food losses is one way to achieve this.

Therefore, the aim of this study is to evaluate the postharvest quality and incidence of losses of tomatoes at the retail level and during consumer simulated storage. The specific objectives were to; (i) estimate the incidence of tomato postharvest physical losses (ii) quantify the changes in physico-chemical properties related to quality during storage, and (iii) estimate the economic and environmental impacts of the losses.

Materials and methods

Sample material

Tomatoes were purchased from three major retail outlets (two supermarkets and one street market vendor) in Stellenbosch, South Africa. This was conducted during the summer season of February 2011. A total of 750 units (~75 kg) of tomatoes were purchased from each Outlet. Produce from each Outlet was then randomly divided into five equal batches of 150 units (~15 kg) each. One batch was analysed before storage, two batches were kept at ambient conditions (22 – 25ºC, 52 – 57% RH) and the other two in recommended cold temperature (10 - 12ºC, 92 – 96 % RH). The stored batches were analysed on days 3 and 7, respectively. On each day of analysis, tomatoes from each respective outlet were evaluated for external quality after which 15 units (~ 1,5 kg) were cut, blended and stored at -80 °C into an ultra-low temperature freezer (New Brunswick Scientific, England). The frozen samples were used for the analysis of the following parameters; total soluble sugar (°Brix), titratable acidity, ascorbic acid, total carotenoids. For proximate analysis only freeze dried samples were used.

Environmental conditions and pulp temperature

The conditions inside each retail outlet were determined using Tinytag Explorer temperature (-25 to 50°C) and relative humidity (0 to 100%) loggers (Gemini data loggers, UK). Tomato pulp temperature was measured inside each retail outlet using a FoodPro Plus temperature probe (Raytek Corporation, Santa Cruz, CA, USA) and this had a temperature range of -40 to 200 ºC.

Postharvest losses

Each of the five batches was divided in triplicate sub-groups (40 units each) for visual quality assessment (cosmetic appearance, decay and any other mechanical disorders). Decay and severe mechanical injury compromise the safety of fresh vegetables especially if they are to be incorporated into raw dishes. Therefore any produce that had decay and severe injury was regarded as loss. The economic value of the loss was calculated using the respective retail prices from each Outlet. Physical loss evaluation was only conducted on days 0 and 3 of storage. Tomatoes analysed on the day of procurement represent retail quality and losses. Those assessed during the post retail storage period simulate the post-purchase practices of consumers.

Weight loss

A total of 15 tomatoes of uniform size and colour (representative of the five batches combined per retail outlet) were randomly selected on arrival for each storage temperature regime to be monitored over 7 days. Percentage weight loss was determined by subtracting sample weights from their initial recorded weights and presented as a percentage of the initial weight. This was done using a precision scale with an accuracy of ± 0.01 g (Mettler Toledo scale).

Colour

Objective colour measurements were performed on both sides of the tomato using a Chromameter CR-400 Konica Minolta (Sensing Inc, Japan) after standardizing the sensor with a white standard tile (Y = 94.00; *x* = 0.13141; *y* = 0.321). The measured colour was expressed as L* (lightness), a* (redness and greenness), b* (yellowness and blueness). Chroma values were calculated as $(a^{*2} + b^{*2})^{1/2}$ and Hue angle as $\tan^{-1}(b^*/a^*)$. A total of 15 tomatoes (~1500g) per outlet, of uniform size and colour were randomly selected from both ambient room and cold room conditions respectively. The colour measurements were taken over 7 days, on days 0, 3 and 7 respectively. The net colour difference, ΔE, was calculated as follows; $\Delta E^* = (\Delta L^{*2} + \Delta a^{*2} + \Delta b^{*2})^{1/2}$ (López *et al.*, 1998; García & Calixto, 2000).

Firmness

Non-destructive compression measurements were performed using a texture analyser (TA.XT. Plus, Exponent Stable Micro Systems, UK). Flat plate compression was applied at a speed of 0.5 $mm.s^{-1}$ to a maximum force of 50 N. Using this set up the distance (5mm) was determined. Singular compression measurements were performed on the equator of the tomato to avoid potential interference of consecutive compression measurements on the results. A total of 15 tomatoes from each of the five batches (per Outlet) were used.

Chemical Analysis

Total soluble sugars (°Brix)

The total soluble solids (TSS) content was determined using a digital refractometer (Atago, Japan) calibrated at 23ºC on tomato juice filtered using a muslin cloth.

Titratable acidity (TA)

Acidity was determined by titration of 2 mL of the filtered tomato juice with 0.1M sodium hydroxide solution up to pH 8.2 using 862 compact titrosampler (Metrohm 862, Herisau, Switzerland). Results were expressed as percentage citric acid in fresh material.

Total carotenoids

The total carotenoids were measured using a spectrophotometric method (Opiyo & Ying, 2005). Samples (1 g) of blended (AEG Electrolux, China) tomatoes were extracted by grinding in 14 mL solution of n-hexane: acetone (3:2 v.v-^{1}), prior to centrifuging the homogenate at 10 000 g for 10 min at 4 ºC in an Eppendorf centrifuge (Mark Chemicals, (Pty) Ltd, South Africa). Supernatant was then collected and topped up to a volume of 25 mL with the extraction solution. Absorbance was determined using a spectrophotometer (Helios Omega UV-Vis Thermo Scientific, USA). Pigment contents were calculated from the following equations:

$$\text{Total Carotenoids } (\mu g.g^{-1}) = \frac{OD_{502} \times 4}{\text{Mass of Sample (g)}} \times 1000 \qquad 1$$

$$\text{Total Lycopene } (\mu g.g^{-1}) = \frac{OD_{502} \times 3.12}{\text{Mass of Sample (g)}} \times 1000 \qquad 2$$

Pigments were calculated as µg.g^{-1} and later presented as mg.100g^{-1} of fresh weight (FW).

Ascorbic acid

Total ascorbic acid was content determined using the 2,6 dichloroindophenol (DCP) titration method under subdued light as according to AOAC (2006) method 967.21.

Proximate composition

All components were determined using standard analytical methods (AOAC, 2005) as follows: moisture (925.09), dietary fibre (993.21), protein (960.52), fat (920.85) and ash (923.03). A conversion factor (6.25) was used to determine the actual protein content of each sample by the Kjedahl method (N*6.25).

Estimated environmental Impacts of postharvest losses

Total green house gas emissions were calculated using values provided by Gonzàlez *et al.* (2011). For every one kg of tomatoes produced and transported to the retail market approximately 0.37 kg of CO_2 is emitted into the atmosphere (Gonzàlez *et al.,* 2011). The energy cost for producing and marketing the lost produce was obtained using a reference value of 3.00 MJ.kg^{-1} also provided by Gonzàlez *et al.* (2011). The water foot print was determined by multiplying the quantity of lost produce with the reference water foot print value of 116 m^3 per t provided by Mekonnen & Hoeskstra (2011).

Statistical analysis

Analysis of variance was performed using SAS version 9.1 (SAS Institute, 2006, Cary, USA). Significant differences between treatment means were assessed using Fisher's least significant-difference test. Variations were compared between retail outlets, storage conditions and over time. All values are presented as means and their standard error.

Results and discussion

Tomato prices and retail conditions

The average price of tomatoes from the three retail outlets was R9.67 per kg. As expected, the supermarkets had the highest selling prices compared to the outdoor market (Table 1). Relative humidity ranged from 37.88 to 59.79% although according to Nunes (2008), the recommended humidity for holding and storing tomatoes in all stages of maturity is 85 to 95%. Low RH has a significant effect on physiological processes such as transpiration rate in fresh produce under various storage conditions, resulting in weight loss (Kader, 2002; Mahajan *et al.*, 2008; Nunes *et al.*, 2009). Weight loss of 3 – 6% will induce wilting, shrivelling and dryness, contributing to a marked loss in quality and economic value (Cantwell *et al.*, 2002; Nunes & Edmond, 2007).

Air conditions for all the retail outlets were not within the recommended optimum storage conditions (10 -12ºC, >80% RH) for tomatoes (Kader, 2002; Nunes-

Table 1 Environmental conditions encountered in three retail outlets on purchase of tomatoes

Retailer	Retail Characterisation				
	Price ($R.kg^{-1}$)	**Air RH (%)**	**Air Temperature (ºC)**	**Produce Temperature (ºC)**	**Source Type**
Outlet 1	10.00	59.79 ± 4.86^{a}	26.68 ± 0.92^{b}	22.46 ± 0.40^{b}	Supermarket
Outlet 2	11.00	54.10 ± 3.10^{a}	26.34 ± 0.93^{b}	19.42 ± 0.49^{c}	Supermarket
Outlet 3	8.00	37.88 ± 0.82^{b}	36.45 ± 0.19^{a}	26.38 ± 0.00^{a}	Outdoor market

^{a,b} Values in a column without a common superscript are significantly different **(P<0.05)**.
*The values are given as means of triplicate determinations ± standard error.

Air temperatures recorded in the three outlets (26.34 – 36.45 °C) had an average of 29.82 °C (Table 1). The highest temperature recordings were found in the outdoor -, --2008). market. In contrast, the recommended retailing temperature for ripe tomatoes should be between 10 to 12.5°C for no longer than 10 days so as to guarantee a normal postharvest shelf life (Nunes, 2008). At temperatures above 10°C, ripening of tomatoes is rapid while produce shelf life is shortened. Ripe tomatoes may be held at ambient room temperature for up to 5 days however those purchased from a retail outlet and stored at room temperature retain best eating quality for 2 to 3 days (Parnell *et al.*, 2004). Therefore, the tomato retailing conditions observed in the present study would provide a shelf life of no more than 5 days with produce from the outdoor market being the most affected.

Produce pulp temperatures also differed for all the outlets ranging from19.42 – 26.38 °C (Table 1). Tomatoes from the outdoor markets had the highest pulp temperatures. Variations in pulp temperature can also be recorded in produce from the same display (Nunes *et al.*, 2009). The store conditions and location of tomatoes on the same retail display can contribute to variation in pulp temperatures of up to 20 °C or more (Nunes *et al.*, 2009). Adequate spacing and ventilation is important to allow temperature management for produce on display including those at the bottom of the shelf (Nunes *et al.*, 2009). This highlights the importance of an optimum cold-airflow system to maintaining the freshness of produce on retail shelves. In the present study, although none of the three outlets had an optimal storage environment for tomatoes, conditions for Outlet 3 were the most unfavourable in terms of both temperature and RH.

Tomato quality

Quality assessment for the tomatoes was classified based on their appearance into good, decayed and mechanically damaged produce as presented in Fig. 1.

Postharvest loss at retail and consumer levels

Postharvest losses in vegetables are closely related to handling, from harvest to retail (Ferreira *et al*., 2005). Tomato losses direct from retail outlets ranged from 12.50 – 18.16% with an average of 14.46% (Table 2). The losses observed in this study are comparable to other retail losses ranging from 3 – 37% reported in literature (Udas *et al*., 2005; Genova *et al*., 2006abc; Barry *et al*., 2009; Nunes *et al.*, 2009; Kitinoja *et al*., 2010).There were no significant (P<0.05) differences with

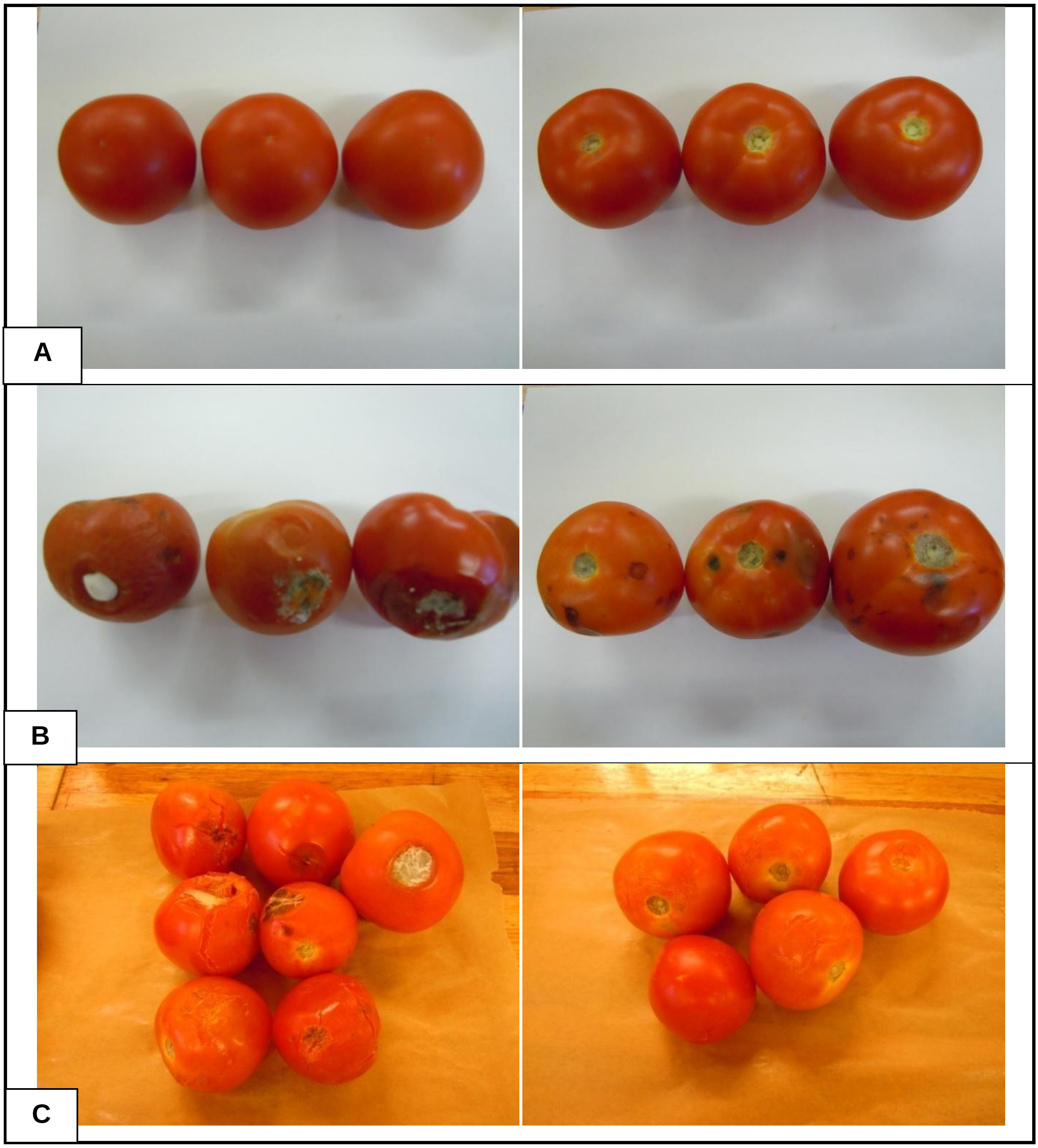

Figure 1 Photographs of representative tomato quality classified as (A) good, (B) decayed and (C) mechanically damaged tomatoes.

Table 2 Postharvest losses (%) of tomatoes from three retail outlets stored at ambient (22 - 25˚C; 52 – 57% RH) and optimum (10 - 12˚C; 92 - 96% RH) over time

Source	Storage Condition		Overall Loss*	Causes contributing to loss		
	Duration (Days)	Temp ºC		Bruised	Cracked	Decayed
Outlet 1	0	**	18.16 ± 2.90^{b}	37.39 ± 4.83^{bc}	10.06 ± 5.56^{cd}	52.55 ± 9.98^{a}
	3	10 – 12	4.96 ± 0.32^{c}	28.80 ± 4.75^{cd}	61.65 ± 2.76^{a}	16.67 ± 3.60^{bc}
		22 – 25	17.31± 6.57^{bc}	22.19 ± 13.54^{bcd}	23.04 ± 10.83^{bc}	48.16 ± 24.37^{ab}
Outlet 2	0	**	13.02 ± 3.92^{bc}	0.60 ± 0.10^{e}	37.76 ± 15.16^{b}	61.64 ± 15.25^{a}
	3	10 – 12	13.68 ± 4.42^{bc}	41.02 ± 1.20^{b}	11.34 ± 3.70^{cd}	47.64 ± 2.60^{ab}
		22 – 25	16.80 ± 3.20^{bc}	16.34 ± 6.03^{de}	15.90 ± 8.42^{cd}	67.76 ± 12.25^{a}
Outlet 3	0	**	12.50 ± 3.13^{bc}	88.88 ± 0.00^{a}	0.00 ± 0.00^{d}	11.12 ± 0.00^{c}
	3	10 – 12	36.93 ± 5.95^{a}	92.36 ± 0.79^{a}	0.00 ± 0.00^{d}	7.64 ± 0.79^{c}
		22 – 25	38.71 ± 5.83^{a}	80.41 ± 2.74^{a}	0.00 ± 0.00^{d}	19.69 ± 2.74^{bc}

[a,b,c] Values in a column without a common superscript are significantly different (p< 0.05).
*The values are given as means of triplicate determinations ± standard error.
**Losses calculated on day 0.

regards to the losses for all three outlets. Decay accounted for at least 50% of the losses for tomatoes from the supermarkets (outlets 1 and 2) while almost 90% of the outdoor market tomatoes (Outlet 3) were due to severe bruising. A lower incidence of decay (11.12%) was observed for tomatoes from Outlet 3 compared to the outlets 1 and 2. Tomato cracking accounted for 10.06 – 37.76% of physical losses for the supermarkets and was not observed in produce from Outlet 3. One may infer that the outdoor dealer handles lower volumes of vegetable produce per period. This allows them to easily sort the produce for decay. On the other hand larger produce volumes make it more difficult for supermarkets to sort for decay and mechanical injury.

Mechanical injuries, inadequate storage, rough transit handling, and on-display time in retail markets have been identified as some of the major causes for vegetable postharvest losses (Nunes & Edmond, 2002; Ferreira *et al*., 2005). Mechanically damaged fresh vegetables are unsightly and symptoms include bruises, cuts, cracks and punctures which in turn facilitate decay and enhanced water loss (Kader & Rolle, 2004; Bollen, 2006; Adeoye *et al.*, 2009; Mbuk *et al.*, 2011). A study conducted by Mbuk *et al.* (2011) established that careless handling during loading and off-loading of tomatoes, contributed to breakages (18%) and the undesirable softening to another 34% of the whole consignment. Additionally, tomato packages were often squeezed into vehicles preventing good ventilation and as a result over 50% of the consignment was lost (Mbuk *et al.,* 2011).

Throughout the present study, mechanical injury predominantly in the form of bruising was most prevalent in the outdoor market tomatoes. Supermarket losses were found to be from both mechanical injury and decay. The development of decay can be traceable to growing conditions, sanitation and packing house operations as well as undesirable temperatures and time delays after harvest (Kader, 2002).Tomato temperature management is a key important factor in postharvest quality control systems (Kader, 2002; Nunes & Edmond, 2002; Toor & Savage, 2006). The recommended transit and storage temperature for tomatoes is 10 – 18˚C and anything below this temperature range will cause chilling injury while too warm conditions promote abnormal ripening and accelerated deterioration (Kader, 2002; Toor & Savage 2006; Nunes *et al.*, 2009).

Post retail storage temperature had a significant ($P<0.05$) effect on the magnitude of tomato losses over time. Tomato losses after three days of consumer simulated storage ranged from 4.96 – 36.93% under refrigerated condition (10 – 12˚C; 92 – 95 %RH) and were higher (16.80 – 38.71%) at ambient condition (22 –

25˚C; 52 – 57 %RH). The variation in physical losses during storage can be attributed to the different supply chain systems and the types of cold chain management used by the retailers. Physical loss evaluation had to be discontinued after the 3rd day of consumer storage as the tomatoes, especially form Outlet 3, became totally unusable due to rots and decay in both storage conditions.

Tomato losses at retail level for Vietnam, Cambodia and Lao PDR ranged from 3 – 7% (Genova *et al.*, 2006abc) and these were attributed to poor cold chain management and inadequate postharvest technology systems. Another study conducted by Kitinoja (2010) in four developing countries; Ghana, Benin, Rwanda and India revealed that use of inappropriate packaging coupled with poor temperature control management contributed to tomato losses of 14.7 – 26.4% at the retail level alone.

Tomatoes from Outlet 3 experienced the highest physical losses (36.93 – 38. 71%) in either storage treatment compared to the supermarkets. The very handling of tomatoes during harvesting, grading, packing and the type of transit storage conditions all have a cumulative effect on the final quality of tomatoes on the retail shelf and at consumer level (Kader, 2005; Kitinoja, 2010). Furthermore, the use of recommended temperature storage conditions only helped to maintain as much of the original inherent postharvest quality as possible, by suppressing physiological activity of plant tissues and the activity of spoilage microorganisms (Nunes & Edmond, 2007). However, quality of fresh produce cannot always be amended by optimal storage conditions as was observed in this study. Therefore, the maximum storage life of any fresh produce is dependent on other factors which include production history, maturity stage at harvest and inherent qualities (Kader, 2005).

Weight Loss

The intensity of weight change during storage is time and temperature dependent (Javanmardi & Kubota, 2006). Tomatoes stored at ambient condition (22 – 25 ºC; 52 – 57 %RH) lost weight faster than those in cold store (10 – 12 ºC; 92 – 95 %RH). Weight loss continued to increase with storage time. At the end of the seven days storage period, tomatoes stored at lower temperature conditions experienced a weight loss of 1.11%, while those stored at ambient condition showed losses of 4.65%. The rate of weight loss was significantly ($P<0.05$) highest for tomatoes from the Outlet 3 compared to those from the supermarkets for all storage conditions. The

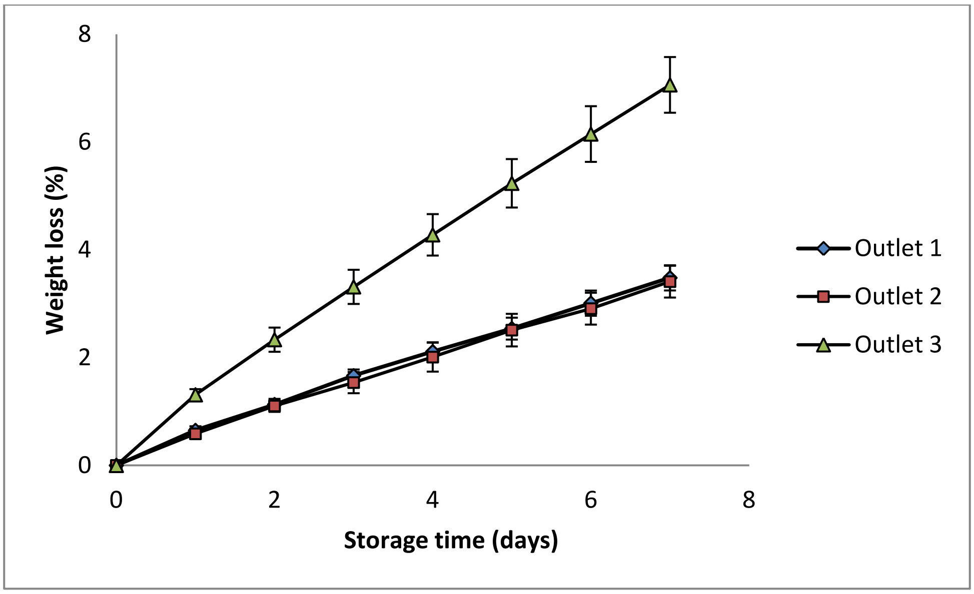

Figure 2 Weight loss of tomatoes during from three different retailers stored at ambient condition (22 – 25 ˚C; 52 – 57 %RH) for a period of 7 days.

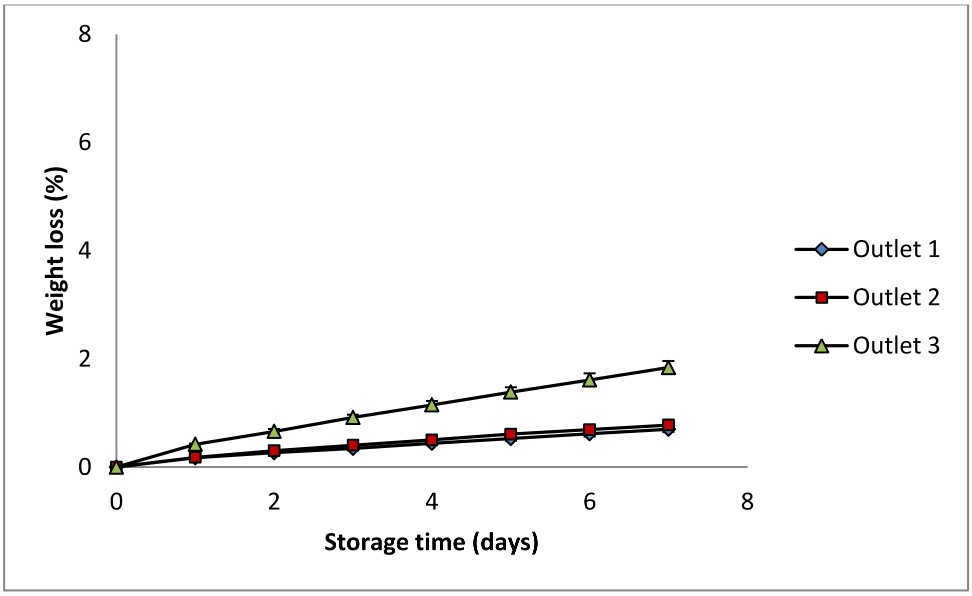

Figure 3 Weight loss of tomatoes during from three different retailers stored at optimum cold condition (10 – 12 ˚C; 92 – 95 %RH) for a period of 7 days.

major factors contributing to postharvest weight change in vegetables are transpiration and respiration (Bhowmick & Pan 1992).

Transpiration occurs through vapour pressure deficit of water, which is a function of air temperature, pressure, and relative humidity. Respiration causes weight reduction through the conversion of carbon atoms into atmospheric carbon dioxide (Bhowmick & Pan 1992; Javanmardi & Kubota, 2006). Furthermore, a significant correlation exits between weight loss and visual quality attributes of tomatoes (Nunes & Edmond, 2007). Postharvest water loss of vegetables can lead to wilting and shrivelling, which reduces market value and consumer acceptability. The study by Nunes & Edmond (2007) detected objectionable softening and overripe appearance of tomatoes at 2% weight loss. Accordingly a temperature controlled environment is necessary for the keeping quality of tomatoes as well as for reducing substantial economic losses during at the consumer level.

Colour

The degree of redness a* (13.09 – 21.26) varied significantly ($P<0.05$) between the outlets (Table 3). This could be attributed to the different ripening stages of the tomatoes. Produce from Outlet 2 had the most intense red colour (a*) while that from Outlet 1 showed the least degree of ripened red colour. Tomatoes from Outlet 1 had the highest intensity of lightness (L*) and least chroma (C*) value on the day of purchasing. Tomatoes continue to ripen during storage and this is characterised with increasing redness (a*) (Kader, 2002; Javanmardi & Kubota, 2006). Tomatoes kept in ambient condition (22 – 25 ºC; 52 – 57 %RH) were the most ripened compared to cold store (10 – 12 ºC; 52 – 57 %RH). The ambient temperature conditions provided the most conducive environment for tomato ripening. As the tomatoes ripened the lightness (L*) and hue angle (Hº) also decreased. Overall colour change (ΔE) was generally higher for ambient stored produce (6.10) compared to cold store (5.88) although there were no significant differences after 7 days of storage.

Firmness

Tomato firmness ranged from 10.30 – 21.78 N at the time of purchasing and was highest for Outlet 1 followed by outlets 2 and 3, respectively. There was a general reduction in firmness for all the tomatoes due to continued produce ripening (Table 3). At day 3 of storage, firmness losses for cold (10 – 12 ºC) and ambient (22 – 25 ºC) conditioned tomatoes were 13.85% and 41.07% respectively. After 7 days of

Table 3 Colour and Firmness changes in tomatoes from three retail outlets stored at ambient (22 – 25 ˚C; 52 – 57 %RH) and cold temperature (10 – 12 ˚C; 92 – 95 % RH) conditions for 7 days.

Retail	Storage Condition		Colour Values						Firmness (N)
	Time (Days)	Temp (ºC)	L*	a*	b*	C*	H°	∆E	
Outlet 1	0	**	44.20± 0.38^{a}	13.09 ± 0.48^{j}	20.71 ± 0 .48^{f}	24.59 ± 0.63^{d}	57.87 ± 0.36^{a}	0.00 ± 0.00^{f}	21.78 ± 0.63^{a}
	3	10 - 12	42.12 ± 0.89^{bc}	17.87 ± 0.47^{i}	21.91 ± .37^{ef}	28.33 ± 0.51^{c}	50.91 ± 0.50^{bcd}	5.48 ± 0.38^{bc}	18.75 ± 0.57^{g}
		22 -25	40.08 ± 0.88^{ef}	18.88 ± 0.52^{gh}	21.69± 0.51^{f}	28.81 ± 0.67^{c}	48.98 ± 0.50^{cde}	7.26 ± 0.40^{ab}	11.11 ± 0.38^{c}
	7	10 - 12	40.75 ± 0.92^{de}	18.22 ± 0.36^{hi}	21.42± 0.34^{f}	28.15 ± 0.44^{c}	49.66 ± 0.39^{cde}	6.24 ± 0.11^{ab}	17.48 ± 0.50^{d}
		22 -25	39.08 ± 0.75^{fg}	19.21 ± 0.75^{g}	20.44 ± 0.79^{f}	28.07 ± 1.04^{c}	46.81 ± 0.50^{e}	8.01± 0.20^{a}	8.04 ± 0.35^{h}
Outlet 2	0	**	45.28 ± 1.64^{a}	21.26± 0.32^{cd}	29.08 ± 0.50^{a}	36.51 ± 0.54^{a}	54.06 ± 0.46^{ab}	0.00 ± 0.00^{f}	19.81 ± 0.30^{b}
	3	10 - 12	42.89 ± 1.01^{b}	21.66 ± 0.56^{bc}	26.89 ± 0.68^{b}	34.90± 0.85^{ab}	51.24 ± 0.47^{bc}	3.41 ± 0.15^{cde}	16.99 ± 0.31^{d}
		22 -25	41.10 ± 1.54^{cde}	21.96 ± 0.58^{abc}	26.35 ± 1.67^{bc}	34.54 ± 1.66^{ab}	50.05 ± 0.96^{cde}	5.10 ± 0.12^{bc}	12.95 ± 0.34^{f}
	7	10 - 12	40.04± 1.16^{ef}	22.46 ± 0.49^{ab}	23.76 ± 0.50^{de}	32.90± 0.66^{b}	46.36 ± 0.43^{e}	7.86 ± 1.62^{a}	15.18 ± 0.16^{e}
		22 -25	41.43 ± 194^{cd}	22.53 ± 0.47^{a}	24.93 ± 0.59^{cd}	33.83 ± 0.68^{ab}	47.66 ± 0.62^{cde}	6.40 ± 1.68^{ab}	10.61 ± 0.06^{g}
Outlet 3	0	**	38.24 ± 0.88^{gh}	19.46 ± 0.65^{fg}	22.04 ± 0.59^{ef}	29.69 ± 0.81^{c}	49.78 ± 0.61^{cde}	0.00± 0.00^{f}	10.30 ± 0.03^{g}
	3	10 - 12	37.34 ± 0.95^{hi}	19.58 ± 0.58^{fg}	20.96 ± 0.55^{f}	28.89 ± 0.72^{c}	47.95 ± 0.57^{cde}	1.60 ± 0.43^{ef}	8.93± 0.33^{h}
		22 -25	36.91 ± 1.11^{i}	20.06 ± 0.39^{ef}	20.49 ± 0.49^{f}	28.86± 0.59^{c}	46.53 ± 0.35^{e}	2.42 ± 0.35^{de}	6.22 ± 0.14^{i}
	7	10 - 12	37.82 ± 0.84^{ghi}	20.09± 0.57^{ef}	21.27 ± 0.52^{f}	29.37 ± 0.70^{c}	47.02 ± 0.57^{de}	3.54 ± 1.14^{cde}	8.69 ± 0.19^{h}
		22 -25	36.90 ± 1.15^{i}	20.54 ± 0.53^{de}	21.27 ± 0.95^{f}	29.63 ± 0.94^{c}	46.32 ± 0.84^{e}	3.88 ± 1.08^{cd}	5.08 ± 0.25^{j}

^{a,b,c} Values in a column without a common superscript are significantly different (P<0.05).

All values are given as means of triplicate determinations ± standard error.

**The values given are representative of the retail quality before storage

Table 4 Chemical changes by tomatoes from three retail outlets stored at ambient 22 – 25 ˚C; 52 – 57 %RH) and optimum (10 – 12 ˚C; 92 – 95 % RH) over time (per $100g^{-1}$FW)

Retail	Storage Condition		Component					
	Time (Days)	Temp ºC	Ascorbic acid (mg)	Carotenoids (mg)	Lycopene (mg)	TSS (%)	TA (%)	TSS/TA (%)
Outlet 1	0	**	12.47 ± 0.31[b]	2.04 ± 0.34[i]	0.59 ±0.03[i]	5.80 ± 0.06[a]	0.40 ± 0.01[fgh]	14.50 ± 0.19[a]
	3	10 - 12	13.86 ± 0.21[a]	3.17 ± 0.35[hi]	2.04 ± 0.17[g]	5.73 ± 0.03[a]	0.45 ± 0.01[c]	12.75 ± 0.32[bcd]
		22 - 25	8.39 ± 0.05[f]	8.00 ± 1.09[ef]	3.59 ± 0.14[c]	5.27 ± 0.09[bc]	0.44 ± 0.01[cd]	11.97 ± 0.21[def]
	7	10 - 12	10.54 ± 0.14[c]	3.17 ± 0.35[hi]	2.04 ± 0.17[g]	4.63 ± 0.07[d]	0.52± 0.01[a]	8.97 ± 0.12[h]
		22 - 25	6.79 ± 0.11[h]	11.47 ± 0.35[b]	4.36 ± 0.17[b]	5.10 ± 0.10[c]	0.39 ± 0.00[ghi]	13.19 ± 0.33[bc]
Outlet 2	0	**	9.70 ± 0.06[d]	7.01 ± 0.94[fg]	2.97 ± 0.31[de]	5.50 ± 0.06[ab]	0.49 ± 0.01[b]	11.31 ± 0.30[fg]
	3	10 - 12	8.63 ± 0.02[ef]	8.90 ± 0.31[cde]	1.46 ± 0.21[h]	4.57 ± 0.19[de]	0.39 ± 0.00[ghi]	11.62 ± 0.56[ef]
		22 -25	7.14 ± 0.00[g]	7.75 ± 0.14[efg]	3.27 ± 0.03[cd]	4.60 ± 0.06[d]	0.37 ± 0.01[ij]	12.33 ± 0.28[cdef]
	7	10 - 12	8.56 ± 0.11[f]	9.67 ± 0.09[cd]	2.18 ± 0.06[g]	4.57 ± 0.09[de]	0.44± 0.01[cd]	10.38 ± 0.15[g]
		22 - 25	6.44 ± 0.14[i]	14.77 ± 0.06[a]	4.33 ± 0.02[b]	5.13 ± 0.03[bc]	0.38 ± 0.01[hij]	13.53 ± 0.33[ab]
Outlet 3	0	**	10.70 ± 0.22[c]	4.37 ± 1.16[h]	1.28 ± 0.04[h]	4.20 ± 0.35[e]	0.40 ± 0.01[fg]	10.39 ± 0.72[g]
	3	10 - 12	8.95 ± 0.19[e]	6.27 ± 0.27[g]	5.20 ± 0.28[a]	5.07 ± 0.13[c]	0.48 ± 0.00[b]	10.48 ± 0.25[g]
		22 -25	9.56 ± 0.09[d]	8.27 ± 0.81[def]	2.42 ± 0.21[fg]	4.93 ± 0.22[cd]	0.43 ± 0.00[de]	11.56 ± 0.43[ef]
	7	10 - 12	9.56 ± 0.05[d]	6.93 ± 0.09[fg]	2.77 ± 0.05[de]	5.17 ± 0.07[bc]	0.42 ± 0.01[ef]	12.42 ± 0.42[cde]
		22 - 25	6.28 ± 0.05[i]	10.41 ± 0.23[bc]	3.05 ± 0.02[ef]	5.13 ± 0.07[bc]	0.36 ± 0.01[j]	14.28 ± 0.34[a]

[a,b,c] Values in a column without a common superscript are significantly different (P<0.05).

*The values are given as means of triplicate determinations ± standard error.

**The values given are representative of the retail quality before storage.

storage firmness losses were significantly lower for cold stored produce (15.63 – 23.37%) compared to that experienced by produce kept in the ambient store (46.44 – 63.09%). The findings in this study corroborate with those reported by van Dijk *et al.*, (2005) who recorded tomato firmness losses of around 10 – 12% and 36 – 52% after 5 days of storage in cold store (9 – 12ºC) and ambient store (20 – 25ºC), respectively.

Chemical Attributes

Ascorbic acid

At purchase, the ascorbic acid content ranged from 9.70 – 12.47 mg.100g^{-1} with an average 10.96 mg.100g^{-1} of fresh weight (Table 4). The ascorbic acid concentration differed significantly for all the retail sources, and was highest for Outlet 1. According to a study conducted in India, the recommended dietary allowance (RDA) of ascorbic acid for adults is 40 mg (Gupta & Bains, 2006). This means that 100 g of tomatoes from the three retail outlets could on average supply 25% of the adult RDA of ascorbic acid. Post retail storage temperature had a significant effect on the changes in ascorbic acid over time. All the tomatoes experienced a gradual reduction in ascorbic acid content regardless of storage condition. However, after 3 days of storage tomatoes from Outlet 1 showed an increase of 11.15% while outlets 2 and 3 had an average decline of 12.18% in cold storage (10- 12 ºC). Tomato ascorbic acid content continues to increase with produce ripening only to decline once the produce starts to senesce or is mechanically stressed (Kader, 2002). Therefore, tomatoes from Outlet 1 were probably the least ripened whilst those from outlets 2 and 3 had already reached their peak maturity ripening stage.

There was a significant ($p<0.05$) decrease in ascorbic acid content for all the tomatoes after seven days of storage. Average losses in cold storage (14.51%) were lower than that for ambient store (68.12%). Extended postharvest storage at elevated temperature conditions has been reported to lower the retention of ascorbic acid of fresh produce particularly in tomatoes (Lee & Kader, 2000; Sablani *et al.*, 2006; Opara *et al.*, 2010). However too low temperatures (<5 ºC) can also cause chilling injury leading to reduction in ascorbic acid (Kader, 2002).

Total carotenoids content

The initial total carotenoid content ranged between 2.04 – 7.01 mg.100g^{-1} of fresh weight (FW) and was highest for tomato produce from Outlet 2 (Table 4). Produce from Outlet 1 had the lowest carotenoid content most probably due to it being the least ripened as evidenced by the low red colour (a*) values observed previously in Table 3. As the storage time increased the carotenoid content for all the tomatoes also increased. A higher average carotenoid content of 12.22 $mg.100g^{-1}$ was observed for tomatoes kept at ambient condition (22 – 25 ºC) compared that (6.59 $mg.100g^{-1}$) of cold store (10 – 12 ºC) after seven days. Javanmardi & Kubota (2006) reported that temperature has a great effect on tomato pigment development. Carotenoid formation in tomatoes has been observed to increase faster at temperatures above 12 ºC, due to the continued ripening (Kader, 2000, Heuvenlink, 2005; Javanmardi & Kubota, 2006). This means that ambient room conditions favoured and increase in carotenoids while low temperature storage actually retarded their production.

Total lycopene content

Lycopene is major carotenoid whose change in concentration can be used to monitor ripening of fresh produce (Heuvenlink, 2005). Initially the lycopene content ranged between 0.59 – 2.97 $mg.100g^{-1}$ and was lowest for Outlet 1 (Table 4). The values obtained are comparatively lower to those reported in literature of 3.2 – 4.2 $mg.100g^{-1}$ (Toor & Savage, 2005; Javanmardi & Kubota, 2006). Tomatoes kept in the ambient temperature conditions developed showed a higher lycopene accumulation with increase in storage time. Average lycopene content (3.91 $mg.100g^{-1}$) for tomatoes kept in ambient condition (22 - 25 ºC) was almost twice that (2.33 $mg.100g^{-1}$) for tomatoes kept at lower temperature (10 – 12 ºC) after 7 days of storage.

Reports in literature also corroborate the findings from this study (Javanmardi & Kubota, 2006; Toor & Savage, 2006). The authors observed increases in tomato lycopene content ranging from 3.2 $mg.100g^{-1}$ to 7.5 $mg.100g^{-1}$ at storage temperatures of 15 – 25 ºC while tomatoes kept below 12 ºC did not experience significant increases from their initial contents of 3.2 – 4.0 $mg.100g^{-1}$over a period of 7 – 10 days (Javanmardi & Kubota, 2006; Toor & Savage, 2006). The results from this study demonstrate lower temperature (10 – 12 ºC) slows down accumulation of lycopene while storing tomatoes in ambient room temperature (22 – 25 ºC) conditions accelerates lycopene development.

Total soluble solids (TSS)

There was a significant ($P<0.05$) difference in TSS for all the tomatoes from the different outlets on the day of purchasing. Total TSS ranged from 4.20 – 5.80% and was lowest for tomatoes from Outlet 3. There was a gradual decrease in TSS for produce from the supermarkets over time. This phenomenon can probably be attributed to the normal senescing causing carbohydrate respiratory losses (Nunes, 2008). Changes in tomato TSS were also significantly different ($P<0.05$) between the storage conditions. However, after seven days of post purchase storage, tomatoes from Outlet 2 and 3 did not show any significant ($P<0.05$) differences in TSS for both cold and ambient storage. Tomatoes form Outlet 1, on the other hand, had a significantly higher TSS in ambient store compared to cold store after seven days. Interestingly, produce from Outlet 3experienced the highest increase in TSS in both storage treatments over time. Increase in TSS can be attributed to ripening (Nunes, 2008). Ripening contributes to the breakdown of pectin substances into more simple sugars thereby increasing the total TSS (Wills & Ku, 2002; Javanmardi & Kubota 2006).

Titratable Acidity (TA)

The major acid constituents of tomatoes are malic and citric acid. Malic acid decreases quickly as produce start to turn red while the citric acid is rather stable throughout the ripening period (Hobson & Grierson, 1993). For this reason TA was determined using citric acid measurements. The TA ranged from 0.40 – 0.49% and was significantly ($P<0.05$) higher for tomatoes from Outlet 1 compared to Outlets 2 and 3 which had similar contents (Table 4). There was a significant ($P<0.05$) reduction in tomato acidity with storage time. Tomatoes kept in ambient condition (22 – 25 ºC) had lower TA (0.38%) compared to that (0.46%) for cold storage (10 – 12 ºC) after seven days of storage. Increased storage temperature has been reported to enhance fruit ripening which is inversely related to the acidity of fresh produce, as organic acids decline with continued ripening (Kader, 2002).

TSS/TA

The flavour and taste of fresh produce is a function of the interaction of the TSS and acidity constituents, which in turn are dependent on produce maturity (Wills *et al.*, 1998). The average TSS/TA for all three retail outlets was 12.07. Outlet 1 tomatoes had the highest TSS/TA (14.50) which was also significantly different from outlets 2 and 3, respectively (Table 4). A high sugar: acid ratio is associated with an excellent flavour (Rees *et al.*, 2012). Low sugar to acid content is associated with a tart flavour. A low acid to sugar levels gives a bland taste (Heuvenlik, 2005; Rees *et al*., 2012). Results from this study showed higher sugar: acid ratio (13.67) for those stored at room temperature (22 – 25 ºC) compared to that (10.59) of cold stored (10 – 12 ºC) tomatoes after 7 days of storage. This is in agreement with the findings of Lu *et al.* (2010). Tomatoes from the outdoor market had the highest (14.28) TSS/TA after 7 days storage most probably because they were also the most over ripened.

Proximate composition

Total proximate composition of the tomatoes purchased from the three different retail outlets is given in Table 5. All the outlets had tomato produce of similar proximate quality; moisture (93.96 – 94.33%), protein (0.78 – 0.80 %), ash (0.46 – 0.52%), fat (0.01 – 0.02%), dietary fibre (0.96 – 1.13%), carbohydrates (3.43 – 3.77%) and dietary energy (71.18 – 73.77 kJ.100g^{-1} FW). The proximate values observed for the tomatoes used in this study are similar to that found in literature for fresh tomatoes (Suarez *et al.*, 2007; Opara *et al.*, 2010).However tomatoes from Outlet 2 had a significantly lower dietary fibre content compared to the other outlets. Only produce from Outlet 2 showed an increase of 27% in dietary fibre while ash content for Outlet 1 increased by almost 35%. Variations in proximate composition over time were most probably due to continued biochemical changes over time (Opara *et al.*, 2010). This could also be a phenomenon of variation in natural physiology whereby some of the tomatoes may have slightly more inherent proximate components than the others (Kader, 2002). There was no change in overall energy. The results show that use of recommended temperature (10 - 12 ºC) and humidity (95%) can help maintain the original quality of fresh produce for days in storage.

Socio-economic impacts of postharvest losses

Economic and environmental impacts of tomato postharvest losses

The value of tomato losses at purchase ranged between R1.00 to 2.15 per kg with highest economic losses occurring for produce from the supermarkets (Table 6). This meant that for every one kg of tomatoes purchased from the three retail outlets approximately R1.53 was lost. Post retail storage condition; cold (10 – 12 ºC) vs. ambient condition (20 –- 25 ºC) also had an effect on the total revenues lost. Overall, ambient storage contributed to higher (R2.23 per kg) economic losses as compared

Table 5 Proximate composition changes of retail tomatoes stored in optimum temperature (10 – 12 ˚C; 92 – 96% RH) over time (g.100^{-1} fresh weight)

Source*		Component*						
		Moisture	**Protein**	**Ash**	**Fat**	**D. Fibre**	**Carbohydrate**	**Energy (kJ)**
Day 0	Outlet 1	93.91 ± 0.27^{a}	0.80 ± 0.07^{a}	0.46 ± 0.04^{b}	0.02 ± 0.01^{ab}	1.05 ± 0.04^{bc}	3.77 ± 1.07^{a}	77.17 ± 4.49^{a}
	Outlet 2	94.33 ± 0.20^{a}	0.78 ± 0.03^{a}	0.49 ± 0.02^{b}	0.02 ± 0.00^{ab}	0.96 ± 0.05^{c}	3.43 ± 0.51^{a}	71.18 ± 2.14^{a}
	Outlet 3	93.96 ± 0.19^{a}	0.82 ± 0.01^{a}	0.52 ± 0.02^{b}	0.01 ± 0.00^{bc}	1.13 ± 0.04^{ab}	3.56 ± 0.54^{a}	73.77 ± 2.25^{a}
Day 7	Outlet 1	93.75 ± 0.43^{a}	0.85 ± 0.06^{a}	0.62 ± 0.03^{a}	0.03 ± 0.00^{a}	1.05 ± 0.06^{bc}	3.71 ± 1.34^{a}	77.31 ± 5.62^{a}
	Outlet 2	94.15 ± 0.04^{a}	0.89 ± 0.01^{a}	0.49 ± 0.00^{b}	0.02 ± 0.00^{b}	1.22 ± 0.00^{a}	3.23 ± 0.16^{a}	69.70 ± 0.66^{a}
	Outlet 3	93.73 ± 0.74^{a}	0.87 ± 0.01^{a}	0.51 ± 0.00^{b}	0.00 ± 0.00^{c}	1.05 ± 0.00^{bc}	2.84 ± 0.06^{bc}	62.27 ± 12.63^{a}

^{a,b,c} Values in a column without a common superscript are significantly different (P<0.05).

*The values are given as means of triplicate determinations ± standard error.

to cold store (R1.65 per kg).Produce from Outlet 3, despite having the lowest selling price, had the highest significant ($P<0.05$) monetary losses by the consumer averaging R3.00 per kg, almost double that for the supermarkets on day 3 of storage. This could be attributed to the high volumes of physical loss observed for tomatoes from the informal market as compared to the supermarkets (Table 2).

Based on the percentage losses of retail tomatoes before and after consumer storage, estimates were made to determine the volume of tomatoes that could be lost at the national retail level. In the year 2010, South Africa produced approximately 540 000 t of tomato produce and of this approximately 50% (255 532 t) went to the National fresh produce markets (NFPMs) for distribution to the local retail outlets (DAFF, 2011). Accordingly, the tomato losses in Table 2 (12.50 – 18.16%) could be equated to an annual loss of 31 940 – 46 410 t valued at R33.99 – 99.75 million using the 2011 domestic supply data of 255 532 t (Table 6). This meant that at least 37 207 t of tomatoes worth R61.65 million retail losses were lost for that year. Tomatoes account for 19% of vegetable production in South Africa and the value of tomato losses would therefore significantly affect the vegetable industry's profits. The overall cost of postharvest losses deprives fresh produce handlers of their optimum revenue and also contributes to an increase in prices so as to cover for the losses (Harris, 1978; Mbuk, 2011).

The environmental impacts of these losses at national retail level were also estimated. Postharvest losses of tomatoes at purchase were found to contribute to 11.82 – 17.17 million tCO_{2eq} (Table 6). To sink the average of these values (13.77 million t $CO_{2eq.}$) it would require planting at least 350 million trees; at 0.039 t CO_2 per urban tree planted (U.S. DOE, 1998). Furthermore, an estimated 95.83 – 139.23 million MJ of fossil energy and 3.74 – 5.43 million m^3 of water were also lost (Table 6). This meant that at least 111.63 million MJ and 4.35 million m^3 were lost. In addition, the national water waste could sustain at least 238 356 individuals daily for a whole year given that the basic water requirement standard to sustain one individual per day is 0.05 m^3 of water (Gleick & Iwra, 1996).

The impact of the losses (Table 6) was lower by 35.15% for tomatoes kept at lower storage temperature (10 – 25 ºC) compared to ambient storage (22 – 25 ºC) highlighting the importance of postharvest temperature management during storage. The losses could also be controlled by reducing the incidence of mechanical injury through careful handling of tomatoes at all times. Pre-sorting of tomatoes especially

Table 6 Postharvest losses impact in terms of magnitude, monetary values, energy used, GHGE and water foot print in the production of tomatoes stored at ambient 22 – 25 ˚C; 52 – 57 %RH) and optimum (10 – 12 ˚C; 92 – 96 % RH) over time.

	Storage Condition		Estimated economic and physical losses			*Estimated environmental and resource impacts		
Retail	Time (Days)	Temp (ºC)	Value (R/kg)	Physical (t x 10^3)	Value (ZAR x 10^6)	Emissions CO_2eq (t x 10^6)	Energy Used (MJ x 10^6)	Water Foot Print (m^3 x 10^6)
Outlet 1	0	**	2.15 ± 0.16^{bc}	46.41 ± 7.41^{b}	99.75 ± 18.73^{b}	17.17 ± 2.74^{b}	139.23 ± 22.22^{b}	5.43 ± 0.87^{b}
	3	10 - 12	0.50 ± 0.03^{e}	12.67 ± 0.82^{c}	6.34 ± 0.79^{b}	4.69 ± 0.30^{c}	38.02 ± 2.47^{c}	1.48 ± 0.10^{b}
		22 - 25	1.73 ± 0.15^{cd}	44.25 ± 16.78^{bc}	79.01 ± 33.69^{b}	16.37 ± 6.21^{bc}	132.74 ± 50.35^{bc}	5.18 ± 1.96^{b}
Outlet 2	0	**	1.43 ± 0.18^{cd}	33.27 ± 10.01^{bc}	51.20 ± 20.36^{b}	12.31 ± 3.70^{bc}	99.82 ± 30.02^{bc}	3.89 ± 1.17^{b}
	3	10 - 12	1.51 ± 0.12^{cd}	34.97 ± 11.30^{bc}	53.89 ± 18.10^{bc}	12.94 ± 4.18^{bc}	104.91± 33.90^{bc}	4.09 ± 1.32^{b}
		22 - 25	1.85 ± 0.35^{c}	42.93 ± 8.18^{bc}	85.09 ± 33.00^{b}	15.89 ± 3.02^{bc}	128.80 ± 24.53^{bc}	5.02 ± 0.96^{b}
Outlet 3	0	**	1.00 ± 0.13^{de}	31.94 ± 7.99^{bc}	33.99 ± 13.12^{b}	11.82 ± 2.95^{bc}	95.83 ± 23.96^{bc}	3.74 ± 0.93^{b}
	3	10 - 12	2.95 ± 0.48^{ab}	94.38 ± 15.22^{a}	293.32 ± 88.26^{a}	34.92 ± 5.63^{a}	283.13 ± 45.65^{a}	11.04 ± 1.78^{a}
		22 - 25	3.10 ± 0.47^{a}	98.93 ± 14.90^{a}	320.31 ± 97.43^{a}	36.61 ± 5.51^{a}	296.80 ± 44.70^{a}	11.58 ± 1.74^{a}

^{a,b,c} Values in a column without a common superscript are significantly different (P<0.05).
*Estimated values obtained using the 2010 volume of tomatoes sold by the NFPMs of 255 532 t
**The values given are representative of the retail quality before storage.

during packing of produce and monitoring adherence to hygiene standards from the onset of harvest to the consumer is important for controlling cross contamination and proliferation of spoilage microorganisms.

Conclusions

Retail displayed tomatoes are easily susceptible to postharvest losses as they have a short shelf life and can be easily damaged by any form of rough mechanical handling. The magnitude of physical losses for tomatoes purchased from three different retail outlets was on average 14.56%. Losses were due to decay and mechanical damage. The estimated volume of this loss is around 37 207 t valued at R61.65 million at the national retail level. Retailing conditions in the outdoor market were the least favourable in terms of both air temperature and relative humidity. The losses observed on the day of purchasing for produce from the supermarkets were, however, comparable to those observed for the informal market. This goes to show that temperature management alone is not enough to curb postharvest losses if the incidence of mechanical injury and practice of strict sanitary hygiene is not met. During post retail storage the losses for produce from Outlet 3 were the highest showing that the supermarket tomatoes had better inherent quality over time.

The ascorbic acid content (10.96 $mg.100g^{-1}$) declined by 12.62% for low temperature (10 – 12 °C) stored tomatoes while those kept at ambient condition (22 – 25 °C) temperature had a decline of 39.70%. Overall colour change, firmness decline and weight loss were all most pronounced for tomatoes that were kept in room temperature. Based on the average individual requirement of at least 2000 kcal (8374 kJ) per day (Story & Stang, 2005), the total physical losses at national retail could meet the daily dietary energy needs of at least 104 360 individuals for a whole month. In addition the tomatoes lost could meet the daily ascorbic acid requirements (40 $mg.day^{-1}$) of at least 254 842 individuals for a whole year.

The environmental impacts of these losses reveal that postharvest losses of tomatoes contribute to the unwarranted emission of approximately 13.54 million t of CO_{2eq} green house gases. As much as 109.76 million MJ (~30.51 million kWh) of fossil energy and 6.85 million m^3 of fresh water resources were also lost. The energy lost is worth R40.56 million given that the minimum Eskom tariff rate is R0.75 per kWh (Eskom, 2012). The fresh water lost could sustain at least 238 356 individuals daily for a whole year at daily minimum usage rate of 0.05m^3 per day. In order to control these losses retailers must invest more in pre-sorting of their produce during marketing and also strictly monitor the quality of their produce before and after placing it on the shelf. These losses have a negative effect on the national production volumes as well as the perceived potential revenue. The severity of the problem is also manifested through the wastage of both energy and water resources as well as contributing to environmental degradation from greenhouse gases.

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Chapter 4

POSTHARVEST LOSSES AND CHANGES IN QUALITY AND NUTRITIONAL VALUE OF CABBAGES FROM RETAIL TO CONSUMER

Summary

Cabbage physical losses at retail purchase ranged from 13.64 – 30.30% with an average of 21.21%. Major causes for the losses stemmed from mechanical injury (65.72%), Insect damage (21.06%), and decay (13.22%). Losses after 7 days of simulated consumer storage were 21.72% and 34.34% for cold (0°C) and ambient (22 – 25 °C) stored cabbages. After 7 days of storage weight loss ranged from 3.83 – 5.60% at 0 ºC and 11.65 – 13.83% at 22 – 25 °C. Cabbage leaf discolouration (∆E) was higher in ambient storage (14.48 – 20.19) compared to 0°C (10.40 – 11.27). At ambient temperature, firmness declined by 14.12 – 28.73%, ascorbic acid declined by 20.54 – 66.02% while chlorophyll levels dropped by 46.67 – 73.07%. This decline was lower for cold stored cabbages with firmness losses of 6.83 – 14.20%; ascorbic acid losses of 8.69 – 15.54%; and chlorophyll losses of 7.49 – 11.55% being recorded. There was no general pattern in total soluble solids and titratble acidity changes over time. The proximate composition (moisture, protein, ash, fat, carbohydrates, dietary fibre and energy) remained fairly constant after 7 days in optimum storage. At national retail level, the estimated magnitude of these losses were equivalent to wastage of 24 470 t of fresh cabbages valued at R17.74 million as well as 26.92 million MJ of energy and 3.96 million m^3 of fresh water. The water lost could meet the minimum daily requirements of 195 068 individuals for a whole year. Furthermore, the losses contribute approximately 2.94 million tonnes of unwarranted CO_{2eq} to the environment.

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Introduction

Leafy vegetables are amongst the most nutritious food plants that provide essential micronutrients and vitamins to the human diet. They are usually and preferably consumed fresh, either raw or cooked. Common leafy vegetables include the cabbage (*Brassica oleracia*), spinach (*Spinacia oleracea*), lettuce (*Lactuca sativa*) and mustard (*Brassica juncea*). These vegetables are harvested before physiological maturity (before flowering and setting seed) at which time their metabolism is high (Kader, 2002). This together with high moisture content (approximately 90%) makes leafy vegetables especially susceptible to rapid spoilage and deterioration by both physical and biotic agents.

Vegetable production, particularly in sub-Saharan Africa and Asia, is severely constrained by postharvest losses which in turn limit on the volumes of good quality produce reaching the consumers. Reports on the quantitative postharvest losses of cabbage range from 10 to 62 % (Feng, 2001; Zheng, 2001; Pal *et al*., 2002; Udas *et al*, 2009, Gajbhiye, 2008). At least 20 % of the total cabbage production is lost at the farm level while 28 % is lost at the retail level (Kitinoja, 2010). Some of the major causes for the losses include high temperatures during harvest, rough handling of cabbage heads during transit and poor storage conditions. Inadequate pest control management and inadequate nutrient supply during pre-harvest periods are also cited as having a negative impact on the postharvest quality of cabbage (Kanlayanarat, 2007). Often such produce is rejected at the market level as it does meet the required standards (DAFF, 2011).

In the year 2009, global cabbage production was approximately 70 million tonnes and of this South Africa accounted for less than 1% with 150 000 t (DAFF, 2011). China accounts for 53% of global cabbage production followed by India with10% (NHB, 2010). The cabbage industry in South Africa and across the globe is domestically oriented, as cabbage is primarily valued as a fresh vegetable. Domestic distribution of cabbage is predominantly controlled by large supermarkets whose retail prices are correlated to the quality and quantity of produce available (DAFF, 2011). Accordingly, surplus produce supplies are usually associated with a reduction in prices with best quality heads fetching the highest economic returns. Consumers regard good quality cabbage heads as being heavy and solid with bright green outer leaves (Nunes, 2008).

During postharvest period, cabbage heads are regularly trimmed off any damaged and senescing external leaves before sales. This regular trimming results not only in loss of the bright green cabbage colour but also in weight reduction (Nunes, 2008). Trimming of the cabbage leaves during postharvest storage is however inevitable and losses of up to 20% during long term storage can be expected due to moisture loss, leaf discolouration, and decay (Nunes, 2008). Optimal storage conditions for cabbage are 0°C and at least 95% relative humidity (Nunes, 2008). Storage of leafy vegetables at lower than optimal conditions causes chilling injury, internal breakdown, leaf discolouration and abscission (Wills *et al*., 2000).

Global efforts aimed at controlling malnutrition and hunger call for the reduction of any avoidable food losses (FAO, 2011). Given the importance of vegetables in their role towards attaining the millennium development goals (MDGs) it is paramount that the magnitude and incidence of postharvest losses as well as their impacts be understood (Kitinoja, 2010, FAO, 2011). Vegetable production has increased over the years through the use of improved seed and mechanisation (Kader, 2005). However, it may be suspected that the commonly referenced numbers for combined fruit and vegetable losses of 20 – 35% could be either too high or too low (NAS, 1978; Kader 2005). The challenge of not using these figures is that there are no tangible local references to support such claims. Some of the figures are only estimates made by several observers elsewhere and may probably be unique to the specific location where the research was conducted (Kader, 2005, Parfitt *et al*., 2010, Kitinoja, 2010, FAO, 2011). It is thus impossible to make recommendations on ways to improve handling methods or assess the cost-effectiveness of such methods without reliable records.

Therefore, the aim of this study was to evaluate the postharvest quality and incidence of losses of cabbages at the retail level in South Africa. The specific objectives were to: (i) estimate the magnitude of cabbage postharvest physical losses from retail to consumer level, (ii) characterise the changes in physico-chemical quality during storage, and (iii) estimate the environmental impacts of cabbage postharvest losses.

Materials and methods

Sample material

Cabbages of similar cultivar (Farao type) were purchased from three retail outlets (two supermarkets and one street market vendor) in Stellenbosch, South Africa. Produce from each Outlet was randomly divided into five equal batches of 33 units each. One group was analysed before storage, two batches were kept in room temperature storage (22 – 25ºC) and the other two were kept under optimum temperature storage (10 – 12 ºC). The stored batches were later analysed on days 3 and 7 respectively. On each day of analysis, cabbages from each respective Outlet were evaluated for external quality after which sample portions representative of whole cabbage heads (10 per sample) were cut and blended with an Assistant all in one blender, (AEG Electrolux, China) and 1.20 kg of the cabbage blend was stored (using 250ml plastic containers) at -80 °C into an ultra low temperature freezer (New Brunswick Scientific, England). The frozen samples were used for the analysis of the following parameters; total soluble sugar (°Brix), titratable acidity, ascorbic acid, total carotenoids. Samples for proximate analysis were freeze dried prior to analysis.

Retail Conditions

The conditions inside each retail outlet were determined using Tinytag Explorer temperature (-25 to 50°C) and relative humidity (0 to 100%) loggers, (Gemini data loggers, UK).Cabbage pulp temperature was measured (10 units) from inside the outlets using a FoodPro Plus temperature probe (Raytek Corporation, Santa Cruz, CA, USA) and this had a temperature range probe temperature range of - 40 to 200 ºC.

Postharvest loss assessment

External quality examination was carried out by visual inspection for insect damage, severe mechanical damage and decay from triplicate sub-samples (33 units per sample) from each Outlet. Cabbages that had signs of decay or severe insect and mechanical damage were all considered as unfit for consumption. Presence of decay and cracks, compromises the safety of fresh vegetables especially if they are to be incorporated into raw dishes. However consumers can at times cut off the spoilt cabbage head parts and consume the edible portions. Therefore in the case of cabbage losses the overall volume of spoilt cabbages was further divided into two to cater for the edible portions (i.e. if 20% of the cabbages were spoiled, the overall loss would be 10% considering that the remaining 10% was still very edible). Economic loss was calculated by computing the monetary value of the physical loss obtained by expressing the percentage of physical loss as a fraction of the actual selling price of each retail outlet per kilogram of produce.

Weight loss

A total 10 cabbage heads (representative of the five batches combined) from each outlet of uniform size and colour were randomly selected for weight loss evaluation. Each individual cabbage was clearly marked without wounding and its weight monitored (daily) over a period of 7 days using a precision scale with an accuracy of ± 0.01 g (Mettler Toledo scale, Switzerland). Percentage weight loss was determined by subtracting sample weights from their initial recorded weight and presented as a percentage of the initial weight (Javanmardi & Kubota, 2006).

Colour

Objective colour measurements were performed using the CIE (L*a*b*) uniform colour space (CIE-Lab), where L*indicates lightness, a* indicates hue on a green (-) to red (+) axis, and b* indicates hue on a blue (-) to yellow (+) axis (Abbot, 1999). Duplicate colour measurements were taken on either side of the cabbage head equator with a Chromameter CR-400 Konica Minolta (Sensing Inc, Japan) calibrated with a white standard (Y = 94.00; x = 0.13141; y = 0.321). Chroma values were obtained calculated as $(a^{*2}+ b^{*2})^{1/2}$ and Hue angle $\tan^{-1}$ (b*/a*). For each Outlet, three replicates of 11 cabbage heads of uniform size and colour were randomly selected from each storage condition for evaluation. The colour measurements were taken over 7 days, on days 0, 3 and 7 respectively. The net colour difference, ΔE, was calculated as follows; $\Delta E^* = (\Delta L^{*2}+\Delta a^{*2} + \Delta b^{*2})^{1/2}$ as according to López *et al.*, (1998) and García & Calixto, (2000).

Firmness

Destructive texture measurements were performed using a TA-XT Plus texture analyser (Stable Micro Systems, UK). Cutting was applied with a Warner Bratzler blade using a speed of 0.1 mm. $\sec^{-1}$ to a maximum force of 50 N. Using this set up the distance (20 mm) was determined. Cutting measurements were performed on either side of the equator of the cabbage head. A total of 11 cabbages were used per each retail outlet treatment.

Chemical attributes

Ascorbic acid

Total ascorbic acid was determined using the 2,6 dichloroindophenol (DCP) titration method (967.21) as according to the AOAC (2006).

Total caratenoids

The total carotenoid and chlorophyll content were measured using a spectrophotometer method carried out by (Opiyo and Ying, 2005; Opara *et al.,* 2010). Samples (1g) of chopped and then blended (Assistant all in one blender, AEG Electrolux, China) cabbages were extracted by grinding in 14 mL solution of n-hexane: acetone (3:2 v.v^{-1}). The homogenate was then centrifuged at 10 000 g for 10 min at 4ºC in an Eppendorf centrifuge (Mark Chemicals, (Pty) Ltd, South Africa). The supernatant was topped up to a volume of 25 mL with the extraction solution. The absorbance was determined using a spectrophotometer model Helios Omega UV-Vis (Thermo Scientific, USA). Pigment contents were calculated from the following equations:

$$\text{Total Carotenoids } (\mu g.g^{-1}) = = \frac{OD_{502} \times 4}{\text{Mass of Sample (g)}} \times 1000 \qquad 1$$

$$\text{Total Chlorophyll } (\mu g.g^{-1}) = \frac{OD_{645} \times 20.2 + OD_{663} \times 8.2}{\text{Mass of Sample (g)}} \times 1000 \qquad 2$$

Pigments were calculated as µg.g^{-1} and presented as mg.100 g^{-1} of fresh weight.

Total soluble sugars (TSS)

The total soluble solid content (TSS) was determined on muslin cloth filtered cabbage juice using a digital refractometer (Atago, Tokyo, Japan). All values were measured at room temperature and were presented as mean ± S.E.

Titratable acidity

Expressed as percentage citric acid, was determined by titrating 2 mL of filtered (by muslin cloth) cabbage juice with 0.1N NaOH up to pH 8.2 using a TA- Metrohm 862 compact titrosampler (Herisau, Switzerland).

Proximate composition

All components were determined using standard Analytical Official methods (AOAC, 2005) as follows: moisture (925.09), dietary fibre (993.21), protein (960.52), fat (920.85) and ash (923.03). A conversion factor (6.25) was used to determine the actual protein content of each sample by the Kjedahl method (N x 6.25).

Environmental Impact of postharvest losses

Green house gas emissions, total energy values and volume of water associated with lost produce were calculated using values provided in the study by Gonzàlez *et al.* (2011) conducted in Sweden. The production of and transportation of cabbage was reported to emit 0.12 kg CO_2 equivalents for every kg of produce while the energy consumed to produce this was 1.1 MJ. The water foot print was determined by multiplying the quantity of lost produce with the reference water foot print value of 162 m^3 per t provided by Mekonnen & Hoeskstra (2011).

Statistical analysis

Analysis of variance was performed using SAS version 9.1 (SAS Institute, 2006, Cary, USA). Significant differences between treatment means were assessed using Fisher's least significant-difference test. Variations were compared between retail outlets, storage conditions and over time and presented as means and their standard errors.

Results and discussion

Cabbage prices and retail conditions

The size and weight of the cabbage heads differed between the retail outlets with produce weights ranging between 2.24 – 3.32 kg (Table 1). This was probably due to differences in the sources from which the cabbages were procured by the outlets, and cabbage head maturity at harvest. Cabbage produce procured from Outlet 1 had the highest an average head weight of 3.32 kg which meant they were probably more matured (Nunes, 2008). The average retail price per cabbage head was R9.00 per head and was lowest from Outlet 3. The variation in cabbage head weight had a significant ($P<0.05$) effect on the retail prices per unit kg. Accordingly, Outlet 1 (with the biggest cabbage head size) had the lowest selling price per kg of produce (R2.71 kg^{-1}), as compared to Outlet 2 (R3.88 kg^{-1}) and Outlet 3 (R3.57 kg^{-1}), respectively.

Table 1 Environmental conditions and prices in three retail outlets on purchase of cabbages

Retail	Retail Characterisation						
	Price (R/head)	**Price ($R.kg^{-1}$)**	**Head weight (kg)**	**Air RH (%)**	**Air temperature (ºC)**	**Pulp temperature (ºC)**	**Source Type**
Outlet 1	9.00	2.71	3.32 ± 0.15^{a}	61.37 ± 7.48^{a}	20.77 ± 1.80^{b}	7.40 ± 0.15^{a}	Supermarket
Outlet 2	10.00	3.88	2.58 ± 0.13^{b}	62.49 ± 10.41^{a}	21.52 ± 1.65^{b}	8.27 ± 0.33^{b}	Supermarket
Outlet 3	8.00	3.57	2.24 ± 0.35^{b}	31.00 ± 3.60^{b}	31.63 ± 2.20^{a}	14.13 ± 0.57^{a}	Outdoor market

^{a,b} Values in a column without a common superscript are significantly different **(P<0.05)**.

*The values are given as means of triplicate determinations ± standard error.

The environmental conditions were similar for the supermarkets (Outlets 1 and 2) compared to the outdoor market (Outlet 3) (Table 1). The average retail air temperature and relative humidity (RH) were 24.64 ºC and 51.67%, respectively. Outlet 3 had the highest air temperature (31.63 ºC) and lowest RH (31.00%) levels. Correspondingly, the cabbage pulp temperature, a determinant of the produce' metabolic activity, was also highest and almost twice that from the supermarkets, for produce from Outlet 3 (14.13 ºC). It has been shown that increased pulp temperature increases respiration and transpiration from cabbage leaves leading to weight loss and accelerated quality deterioration (Nunes, 2008). The recommended optimum storage conditions for cabbage are >95% RH and 0 ºC (Nunes, 2008). At lower RH levels and high temperatures rate of metabolic activities such as respiration and transpiration are elevated (Kader, 2002). This in turn contributes to excessive water loss, wilting, senescence, decay and death.

Cabbage quality

Quality assessment for the cabbages was classified based on their appearance as good, decayed and or mechanically damaged produce (Fig. 1).

Postharvest losses

Postharvest losses of cabbages (Table 2) were characterised by the presence of insect damage, severe mechanical damage and decay. Cabbage losses before consumer storage ranged from 13.64 – 30.30% with an average of 21.21%. Total physical losses were similar for Outlets 2 and 3, and significantly ($P<0.05$) higher for Outlet 1. These values are comparable to the cabbage retail losses (28.1%) reported by Kitinoja (2010). Severe mechanical damage was a major cause contributing to at least 50% of the retail losses. The presence of mechanical damage was most probably due rough handling during harvesting, loading and offloading of produce.

Mechanical damage of cabbage can occur at any point along the supply chain starting from the point of harvest and has been attributed to the use of inappropriate harvesting tools, poor packaging and rough handling of produce (Kader, 2002; Udas *et al.*, 2005). Decay accounted for 5 – 35% of the supermarket losses. The incidence of insect damage was only observed in cabbages from Outlet 2 (50.95%) and Outlet 3 (12.22%) while. Insect damage is a pre-harvest problem encountered through poor pest control management (Nunes, 2008). Some of the insects and pests that infest

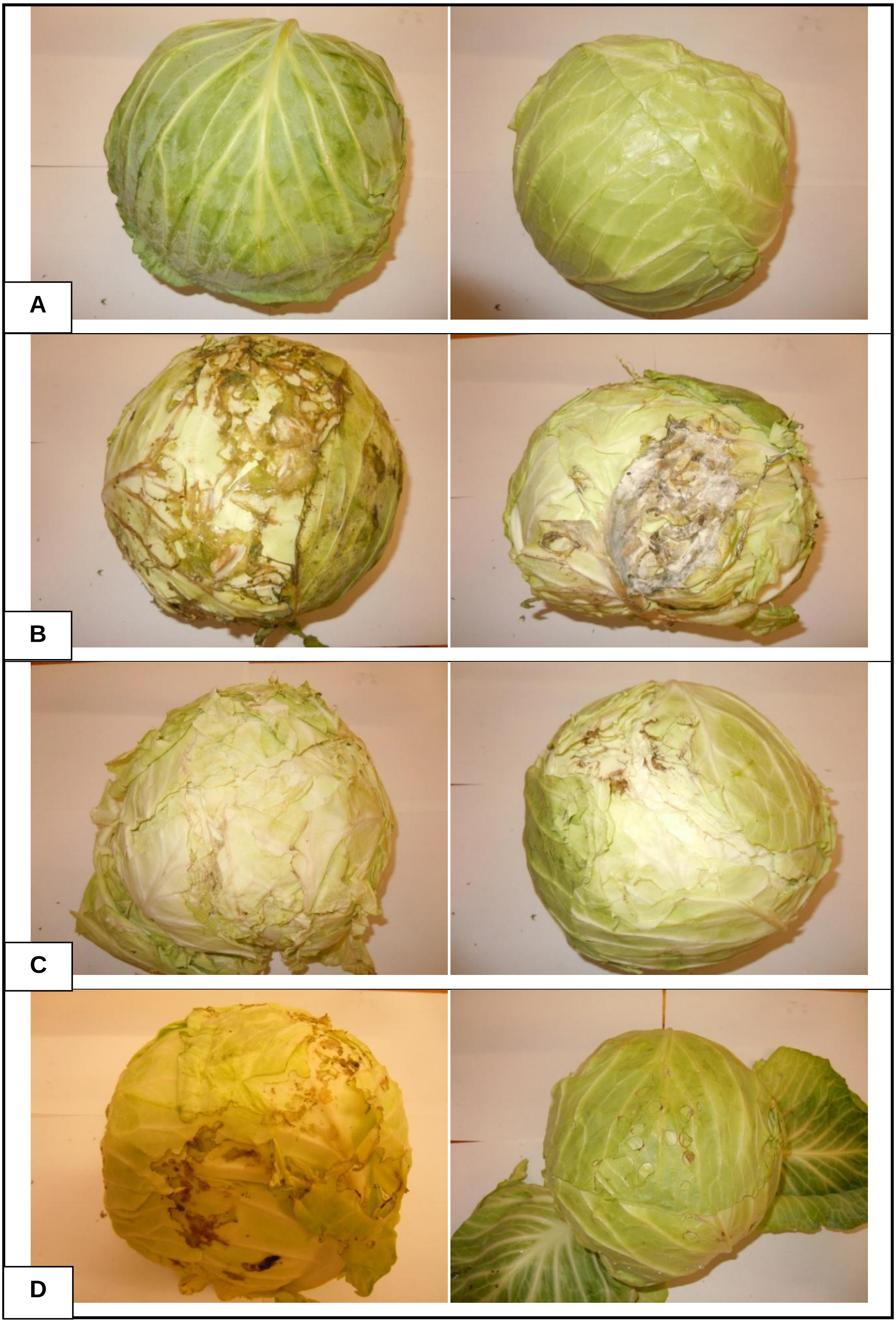

Figure 3 Photographs of representative cabbage quality classified as (A) good, (B) decayed (C) mechanically damaged and (D) insect damaged heads.

Table 2 Postharvest losses (%) of cabbages from three retail outlets stored at ambient (22 – 25 ˚C; 52 – 55%RH) and optimum (10 – 12 ˚C; 91 –- 97 % RH) over time

Retail	Storage Condition		Overall Loss*	Causes contributing to loss		
	Time (Days)	Temp ºC		Insect damage	Mechanical Damage	Decay
Outlet 1	0	**	30.30 ± 1.52^{d}	0.00 ± 0.00^{e}	65.08 ± 4.20^{cd}	34.92 ± 4.20^{b}
	3	0	24.24 ± 1.52^{f}	0.00 ± 0.00^{e}	93.33 ± 6.67^{a}	6.67 ± 6.67^{c}
		22 – 25	33.33 ± 1.76^{c}	0.00 ± 0.00^{e}	91.07 ± 4.49^{ab}	8.93 ± 4.49^{c}
	7	10 – 12	30.30 ± 0.40^{d}	0.00 ± 0.00^{bc}	50.00 ± 4.12^{def}	50.00 ± 4.12^{a}
		22 – 25	46.97 ± 1.52^{a}	0.00 ± 0.00^{e}	51.52 ± 5.97^{def}	48.48 ± 5.97^{a}
Outlet 2	0	**	13.64 ± 0.52^{i}	50.95 ± 4.97^{a}	44.29 ± 2.97^{ef}	4.76 ± 4.76^{c}
	3	0	13.64 ± 0.31^{i}	24.44 ± 12.37^{bc}	75.56 ± 12.37^{abc}	0.00 ± 0.00^{c}
		22 – 25	27.27 ± 0.29^{e}	17.72 ± 2.35^{bcd}	77.51 ± 3.44^{abc}	4.76 ± 4.76^{c}
	7	10 – 12	16.67 ± 0.48^{h}	26.67 ± 6.67^{b}	73.33 ± 6.67^{bc}	0.00 ± 0.00^{c}
		22 – 25	19.70 ± 0.48^{g}	16.89 ± 2.26^{bcd}	37.95 ± 1.07^{f}	45.15 ± 2.89^{ab}
Outlet 3	0	**	19.70 ± 0.76^{g}	12.22 ± 6.19^{cde}	87.78 ± 6.19^{ab}	0.00 ± 0.00^{c}
	3	0	12.12 ± 1.09^{i}	8.33 ± 8.33^{de}	91.67 ± 8.33^{a}	0.00 ± 0.00^{c}
		22 – 25	31.82 ± 0.73^{cd}	29.73 ± 1.84^{b}	64.72 ± 7.37^{cd}	5.56 ± 5.56^{c}
	7	10 – 12	18.18 ± 0.00^{gh}	0.00 ± 0.00^{e}	61.67 ± 7.26^{cde}	38.33 ± 7.26^{ab}
		22 – 25	36.36 ± 0.69^{b}	12.55 ± 1.73^{cde}	43.72 ± 0.87^{f}	43.72 ± 0.87^{ab}

^{a,b,c} Values in a column without a common superscript are significantly different (p < 0.05).

*The values are given as means of triplicate determinations ± standard error.

**The values given are representative of the produce quality on arrival from the outlets.

cabbage plants include cabbage worm (any of numerous insect larvae that feed on cabbages), cabbage moth, cut worm, cabbage aphid, cabbage seed pod weevil and cabbage root fly (Dosdall *et al*., 2001; Dixon, 2009).

During consumer simulated storage, physical cabbage losses averaged 16.67% and 30.81% for optimum (0 °C) and ambient (22 – 25 °C) storage conditions, respectively after 3 days. On day 7 of storage, some of the mechanical bruises and cracks had developed into decay especially for ambient stored produce. The losses had also increased to 21.72% and 34.34% for optimum and ambient storage respectively. Increase in decay could also have been partly due to cross contamination that might have occurred between mechanically damaged produce and spoiled produce. In one study, approximately 60% of a whole cabbage consignment was lost through spreading of black rot causing agents in cabbage produce that had been kept at ambient temperatures (Ceponis *et al*., 1987).

The initial quality of the cabbages has a significant effect on the magnitude of physical losses during post retail storage. Cabbages from Outlet 1 showed the highest incidence of decay and physical losses throughout most of the trial. However, losses for Outlet 1 could partly be attributed to the large average head size which made the cabbages more difficult to handle and be easily prone to mechanical injury. Cabbage losses for cold stored produce from Outlets 2 and 3, which had similar head sizes were comparable however, Outlet 3 had significantly higher losses in ambient storage.

Storage temperatures are important with regards to keeping quality of fresh vegetables. According to Nunes (2008), the appearance of fresh cabbage stored at temperatures of 5 ºC and 20 ºC becomes objectionable after 12 and less than 6 days, respectively. Fresh cabbages can be kept on the retail shelf for at least 3 - 5 days and depending on the quality, after this period they are either trimmed and shrink wrapped or discarded (Pritchard & Becker, 1989; Nunes, 2008). The problem of severe mechanical damage contributed to most of the overall losses and therefore must be traced so as to control the quality of produce that gets to the shelf. This would entail conducting a study that maps the losses and quality of produce from the onset of harvest until it reaches the shelf (Weinberger *et al*., 2008). There is also need for zero tolerance of cross contamination of sound produce with spoiled ones so as to control incidence of cabbage decay. This can be achieved by regular sorting and implementation of strict sanitary hygienic practices.

Weight loss

Cabbage Weight loss correlated positively to increase in storage duration. Overall weight loss after 7 days of storage at 22 – 25°C ranged from 11.65 – 13.83% (Fig. 2) and was at least two times that (3.83 – 5.60%) for produce kept at 0°C (Fig. 3). Cabbages from the supermarkets experienced less weight change compared to those from the outdoor market, presumably due to the controlled temperature environment in the former and was absent for the latter. Visible signs of wilting of the outer cabbage leaves can be detected when weight loss exceeds 5% of the initial weight (Parson *et al*., 1960; Song & Thornalley 2007). The maximum weight loss before cabbage becomes unacceptable for sale ranges between 7 to 10% depending on the cultivar (Robinson *et al*., 1975). Cabbage produce that has lost 7 – 10% of the initial weight is of poor quality in appearance and therefore unmarketable for sale (Robinson *et al.*, 1975; Song & Thornalley 2007). In the current study weight losses in ambient storage rendered the cabbages to be of poor market quality while the optimally kept cabbages retained better visual appearance.

Colour

Tristimulus L* a* b* measurement mode was used as it can relate well to the human eye colour reception (Abbot, 1999). All the cabbages purchased were of similar colour with slight variations in overall green colour 116.23 – 119.06 hue º (Table 3). There was a general decrease of the green colour with increase in storage duration. This was evidenced by the significant ($P<0.05$) increase in a* values as the outer green leaves faded into a pale yellow colour. Overall colour change (ΔE) was higher (14.48 – 20.19) for the produce kept at ambient storage conditions (22 – 25 °C) as compared to that stored at the optimum temperature (10.40 – 11.27) after 7 days of storage. Cabbage from Outlet 3 experienced the highest overall colour change (ΔE) in ambient storage. The de-greening of the cabbages could also be depicted by the decrease in colour saturation C*. The findings from this study corroborate with those found in literature (Pritchard & Becker, 1989; Nunes, 2008). Yellowing of cabbage external leaves was observed to be significantly less rapid at 15ºC than at 20ºC after 6 days of storage (Nunes, 2008). Overall green colour loss (ΔE) was 35 % higher in ambient store than cold store.

Firmness

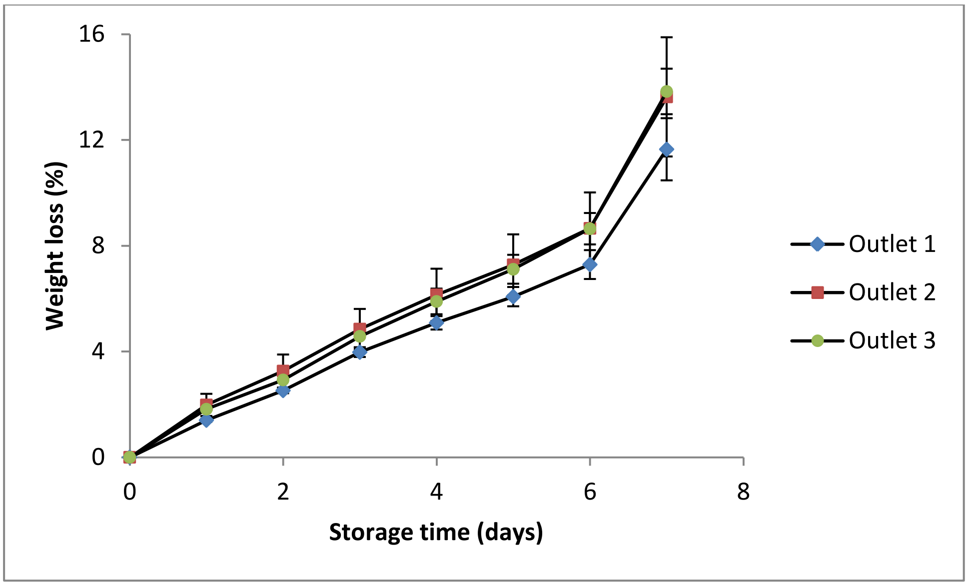

Figure 2 Percentage weight losses over time, of cabbages from three different retailers stored at ambient temperature (22 - 25 ˚C; 52 - 55% RH).

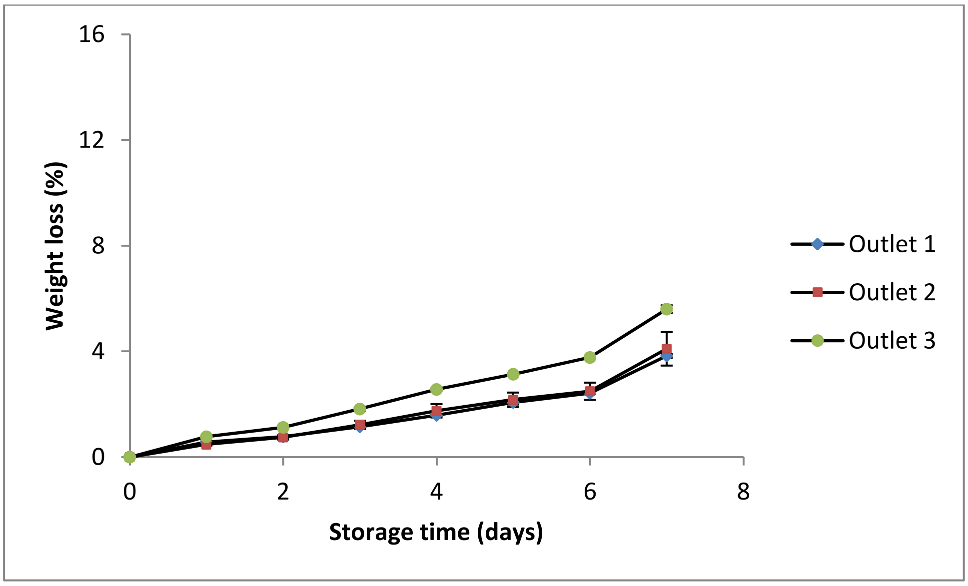

Figure 3 Percentage weight loss over time, of cabbages from three different retailers stored at optimum temperature (0 - 0.5 ˚C; 91 - 97% RH).

Cabbage firmness at purchase ranged from 171.82 – 252.42 N (Table 3). Cabbages from the supermarkets were significantly ($P<0.05$) firmer than those from the outdoor market. During post retail storage, total firmness declined by 2.88% and 16.18% after 3 days of optimum (0 °C) and ambient storage (22 – 25°C) respectively. Total loss in firmness after 7 days of storage in ambient storage ranged from 6.83 – 14.20% and 14.12 – 28.73% for cold storage condition, respectively. Overall firmness losses in ambient store (20.09%) were almost double that for cabbages kept in cold store (10.75%). The type of Outlet had a significant effect on the firm texture of the cabbages during storage. Produce from Outlet 3 had the highest firmness changes just after 3 days of post purchase storage. The harsh outdoor temperature environment could be linked to the rapid quality loss in cabbages from Outlet 3.

Chemical attributes

Ascorbic acid

At purchase all the cabbages had an average ascorbic acid content of 6.21 mg.100 g^{-1} of fresh weight (FW) with a range of 5.13 – 7.63 mg.100 g^{-1} FW (Table 4). Outlet 1 had the highest concentration of ascorbic acid followed by Outlets 2 and 3 respectively. The values obtained are in the range with those observed by Singh *et al.*, (2006), who in their study observed vitamin C content ranges of 5.66 – 23.50 mg.100 g^{-1} of (FW) from eight different cabbage cultivars. In this study, the cabbages had lost 5% and 8% of their initial ascorbic acid content after 3 days of storage in optimum and ambient store conditions respectively.

The cold stored cabbages were able to retain at least 90% of their ascorbic acid after 7 days of storage while ambient stored cabbages had retained only 74%. Overall percentage losses in ascorbic acid concentration were highest for Outlet 3 produce probably due to the fact that the cabbages had been stressed in their former retail storage conditions. The findings from this study agree with the observation made by Albrecht *et al.*, (1990) that at refrigeration temperatures, retention of ascorbic acid by cabbage remains high while at ambient storage the retention is low with as much as 22% of ascorbic acid being lost within one day of harvesting (Vanderslice *et al.*, 1990).

Table 3 Physico-chemical quality changes in cabbages from three retail outlets stored at ambient 22 – 25 ˚C; 52 – 55%RH) and optimum (0 ˚C; 91 – 97 % RH) over time

Retail	Storage Condition		Colour Values						Firmness
	Time (Days)	Temp (ºC)	L*	a*	b*	C*	H°	∆E	
Outlet 1	0	**	72.96 ± 0.04^{g}	-17.65 ± 0.35^{ij}	26.50 ± .10^{f}	29.83 ± 0.12^{j}	117.01 ± 0.30^{cde}	0.00 ± 0.00^{e}	205.17 ± 1.03^{c}
	3	0	73.11 ± 0.15^{g}	-16.29 ± 0.19^{efg}	29.06 ± 0.46^{f}	29.17 ± 0.12^{j}	116.55 ± 0.10^{ef}	9.34 ± 1.17^{d}	197.65 ± 0.95^{cd}
		22 – 25	75.21 ± 0.17^{de}	-13.60 ± 0.33^{a}	31.39 ± 0.18^{c}	31.94 ± 0.15^{gh}	115.29 ± 0.16^{g}	11.03 ± 1.36^{d}	182.73 ± 0.94^{ef}
	7	10 – 12	75.49 ± 0.12^{d}	-16.98 ± 0.30^{ghi}	31.31± 0.36^{c}	35.64 ± 0.26^{b}	118.55 ± 0.33^{b}	11.27± 1.27^{cd}	191.15 ± 3.91^{de}
		22 – 25	79.32 ± 0.14^{b}	-16.78 ± 0.20^{fgh}	33.84 ± .38^{b}	37.94 ± 0.44^{a}	116.47 ± 0.21^{ef}	14.48 ± 1.39^{bc}	176.19 ± 1.50^{fg}
Outlet 2	0	**	72.13 ± 0.12^{h}	-18.01 ± 0.20^{j}	27.77 ± 0.16^{e}	31.01 ± 0.05^{i}	116.23 ± 0.18^{f}	0.00 ± 0.00^{e}	252.42 ± 0.73^{a}
	3	0	74.48± 0.62^{f}	-15.85 ± 0.11^{de}	27.89 ± 0.12^{e}	31.48± 0.18^{i}	115.39 ± 0.13^{g}	9.97 ± 0.98^{d}	255.51 ± 5.22^{a}
		22 – 25	75.62 ± 0.38^{d}	-14.87 ± 0.25^{bc}	29.46 ± 0.21^{d}	33.01 ± 0.37^{ef}	116.72 ± 0.25^{def}	11.06 ± 1.48^{d}	198.35 ± 0.69^{cd}
	7	10 – 12	74.72 ± 0.21^{ef}	-14.79 ± 0.17^{b}	29.17 ± 0.12^{d}	32.78 ± 0.83^{fg}	117.15 ± 0.03^{cd}	10.42 ± 1.11^{d}	224.09 ± 9.95^{b}
		22 – 25	78.45 ± 0.18^{c}	-15.56 ± 0.20^{cd}	35.15 ± 0.20^{a}	38.53 ± 0.34^{a}	114.09 ± 0.17^{h}	14.69 ± 1.17^{b}	179.91 ± 1.79^{fg}
Outlet 3	0	**	64.19 ± 0.30^{k}	-17.16 ± 0.11^{hi}	29.36 ± 0.13^{d}	35.32 ± 0.17^{bc}	119.06 ± 0.19^{b}	0.00 ± 0.00^{e}	171.82 ± 0.95^{g}
	3	0	67.97 ± 0.24^{j}	-15.90 ± 0.49^{de}	29.52 ± 0.17^{d}	34.43 ± 0.29^{cd}	117.44 ± 0.19^{c}	8.63 ± 0.82^{d}	158.11 ± 0.39^{h}
		22 – 25	70.31 ± 0.18^{i}	-14.88 ± 0.21^{bc}	31.14 ± 0.19^{c}	32.73 ± 0.16^{fg}	116.97 ± 0.13^{cde}	10.16 ± 0.89^{d}	146.51 ± 1.92^{i}
	7	10 – 12	69.70 ± 0.10^{i}	-16.95 ± 0.22^{ghi}	29.90 ± 0.15^{d}	33.52 ± 0.11^{def}	120.55 ± 0.29^{a}	10.40 ± 1.45^{d}	147.43 ± 1.84^{i}
		22 – 25	81.66 ± 0.28^{a}	-16.09 ± 0.13^{def}	33.63 ± 1.24^{b}	33.75 ± 0.34^{de}	118.61 ± 0.13^{b}	20.19 ± 2.57^{a}	141.89 ± 0.79^{i}

^{a,b,c} Values in a column without a common superscript are significantly different (P<0.05).

*The values are given as means of triplicate determinations ± standard error.

**The values given are representative of the produce quality on arrival from the outlets.

Total carotenoids

Total carotenoid content ranged from 2.96 – 3.10 mg.100 g^{-1} FW for all three retail outlets and there were no significant P<0.05) differences between them (Table 4). During post retail storage, there were no significant (P<0.05) changes in total carotenoid content for all cabbages over time. However, the cold stored samples had slightly higher (3.51 mg.100 g-1 FW) carotenoid content compared to the average values (2.80 mg.100 g-1 FW) observed for cabbages that had been kept in ambient storage after 7 days.

Chlorophyll

The outer leaf cover plays a very important role with regards to consumer perception of quality and this can be correlated with the chlorophyll content of the external leaves. Bright green cabbage heads are more associated with freshness as compared to pale and lighter ones (Song & Thornalley 2007). Chlorophyll concentrations ranged from 11.91 – 14.78 mg.100 g-1 FW and were lowest for produce from Outlet 3 (Table 4). During post purchase storage, decline in total chlorophyll content was significant (P<0.05) for cabbages kept at ambient storage. Overall green pigment changes in optimum storage were negligible. The low temperatures retarded metabolic activity of the cabbages and helped retain much of the initial produce quality.

Total soluble solids (TSS)

The total soluble solids (TSS) content ranged from 5.67 – 6.30% on day 0, and was lowest for Outlet 3 (Table 4). Changes in TSS content varied for all the outlets during post retail storage. However there was general decline in TSS over time for most the cabbage produce. Nevertheless, ambient stored cabbages from Outlet 2 managed to retain a similar TSS content to that observed before storage. Factors contributing to huge variations in TSS content included among other things crop history; maturity, previous storage period and handling conditions.

Titratable acidity (TA)

Citric acid reported here as titratable acidity (TA) was found to range from 0.07 – 0.08% and was lowest for cabbages from retail outlet 1 (Table 4).Changes in acidity over time varied significantly (P<0.05) for all the retail sources as well as between

Table 4 Chemical changes by cabbages from three retail outlets stored at ambient 22 - 25 ˚C; 52 – 55%RH) and optimum (0 ˚C; 91 - 97 % RH) over time (per $100g^{-1}FW$)

Retail	Storage Condition		Component					
	Duration (Days)	Temp ºC	Ascorbic acid (mg)	Carotenoids (mg)	Chlorophyll (mg)	TSS (%)	TA (%)	TSS/TA (%)
Outlet 1	0**	-	7.63 ± 0.15[a]	2.96 ± 0.16[abc]	14.20 ± 0.73[a]	6.30 ± 0.06[a]	0.07 ± 0.00[h]	95.08 ± 5.81 [a]
	3	0 - 0.5	7.35 ± 0.15[ab]	2.93 ± 0.27[abc]	13.36 ± 0.42[ab]	5.40 ± 0.06[e]	0.08 ± 0.00[ef]	64.95 ± 1.95[cd]
		22 - 25	7.38 ± 0.20[ab]	2.93 ± 0. 27[abc]	11.13 ± 1.04[abc]	5.43 ± 0.03[de]	0.11 ± 0.00[b]	51.03 ± 1.5[e]
	7	10 - 12	7.02 ± 0.14[b]	3.33 ± 0.13[abc]	12.73 ± 1.41[ab]	5.63 ± 0.09[cde]	0.08± 0.00[ef]	50.27 ± 2.34[cd]
		22 - 25	6.33 ± 0.15[c]	2.67 ± 0.35[c]	8.54 ± 2.04[c]	5.00 ± 0.06[f]	0.10 ± 0.00[c]	67.73 ± 1. 68[d]
Outlet 2	0**	-	5.87 ± 0.15[cd]	3.08 ± 0.32[abc]	14.78 ±1.60[a]	6.17 ± 0.9[a]	0.09 ± 0.00[de]	71.44 ± 3.7[bc]
	3	0 - 0.5	5.66 ± 0.19[d]	3.47 ± 0.24[abc]	13.36 ± 0.24[abc]	6.07 ± 0.09[ab]	0.09 ± 0.00[de]	70.23 ± 3.16[bc]
		22 - 25	5.39 ± 0.35[de]	2.93 ± 0.13[abc]	11.38 ± 1.43[c]	5.87 ± 0.22[bc]	0.09 ± 0.00[cd]	67.82 ± 2.82[cd]
	7	0 - 0.5	5.44 ± 0.14[de]	3.33 ± 0. 35[abc]	13.75 ± 1.18[a]	5.73 ± 0.03[c]	0.07 ± 0.00[gh]	78.45 ± 2.98[b]
		22 - 25	4.32 ± 0.15[g]	2.80 ± 0.46[bc]	8.54 ± 2.70[c]	6.27 ± 0.15[a]	0.10 ± 0.00[c]	67.30 ± 2.68[cd]
Outlet 3	0**	-	5.13 ± 0.15[ef]	3.73 ± 0.48[ab]	11.91 ± 0.48[abc]	5.67 ± 0.03[cd]	0.08 ± 0.00[fg]	77.56 ± 3.18[b]
	3	0 - 0.5	4.70 ± 0.15[fg]	3.47 ± 0.27[abc]	11.47 ± 0.27[abc]	5.87 ± 0.07[bc]	0.10 ± 0.00[c]	60.81 ± 1.90[d]
		22 - 25	4.39 ± 0.20[g]	3.47 ± 0.27[abc]	9.76 ± 0.84[bc]	5.83 ± 0.07[bc]	0.12 ± 0.00[a]	50.10 ± 1.83[e]
	7	0 - 0.5	4.44 ± 0.14[g]	3.87 ± 0.35[a]	12.77 ± 1.59[ab]	5.47 ± 0.03[de]	0.08 ± 0.00[fg]	71.55 ± 2.80[bc]
		22 - 25	3.09 ± 0.15[h]	2.93 ± 0.13[abc]	8.12 ± 1.23[c]	5.73 ± 0.03[c]	0.08 ± 0.00[ef]	69.03 ± 3.05[cd]

[a,b,c] Values in a column without a common superscript are significantly different (P<0.05).
The values are given as means of triplicate determinations ± standard error.
**The values given are representative of the produce quality on arrival from the outlets

storage treatments. The TA gradually increased after 3 days of storage for produce from Outlets 1 and 3, with higher values being observed in produce kept in ambient storage. After 7 days of storage produce from outlet 1 continued to show an increase in TA while outlet 2 produce only showed increases in ambient stored produce. Only cabbages from the Outlet 3 had an overall TA content comparable to that of day 0. The huge variance observed in this study could be better understood had the previous storage history of the cabbages been available as some of the cabbages may have been old stock mixed new stocks.

TSS/TA ratio

The sugar: acid ratio on day 0 ranged from 71.44 - 95.08 (%) and it was highest for produce from Outlet 1. Changes in TSS/TA differed significantly for all the Outlets. After 7 days of storage, there was a gradual decrease in the TSS/TA ratio ranging from 1.69 - 31.69% for produce kept at optimum temperature and 5.80 – 47.13% for ambient stored produce. Overall percentage loss in TSS/TA was lowest for produce from Outlet 2 for both ambient and optimum storage conditions. The taste and flavour of cabbage is influenced by changes in organic compounds (Kader, 2002). The change in TSS/TA was correlated to the continued respiration activity of the produce during storage (Hui, 2003). Respiration increases the breakdown of stored reserves of carbon compounds. During anaerobic respiration acetaldehyde is produced which is converted to ethanol. This can lead to the development of alcoholic flavours often termed off-flavours in vegetables (Hui, 2003). The study showed that there is more likelihood for cabbages kept at ambient temperature to change in taste and flavour compared to that stored at lower temperatures.

Proximate composition

The proximate composition of cabbages purchased from all three Outlets is given in Table 5. There was no significant ($P<0.05$) difference in proximate composition; moisture (91.33 -92.97%) protein (1.06 – 1.20%), ash (0.50 – 0.56%), fat (0.03%), carbohydrates (4.39 – 5.32%) and nutritional energy content (92.18 – 110.38 $kJ.100g^{-1}$ FW) for all the cabbage produce at purchase. However, total dietary fibre (1.05 – 1.55%) varied significantly ($P<0.05$) for all the retail sources. During post retail storage some of the proximate composition changed significantly; ash increased by (19.64 – 52.00%), and dietary fibre (12.9 – 74.29%) while fat only

Table 5 Proximate composition changes of retail cabbages stored in optimum temperature (0 - 0.5 ˚C; 91 - 97% RH) over time (per 100 g^{-1} FW)

Source*		**Component**						
		Moisture	**Protein**	**Ash**	**Fat**	**D. Fibre**	**Carbohydrate**	**Energy (kJ)**
Day 0**	Outlet 1	92.97 ± 0.07 [a]	1.06 ± 0.06[ab]	0.50 ± 0.01[c]	0.03 ± 0.00[b]	1.05 ± 0.01[e]	4.39 ± 0.00[a]	92.18 ± 0.93[a]
	Outlet 2	91.33 ± 0.01[a]	1.20 ± 0.06[ab]	0.56 ± 0.02[c]	0.03± 0.00[ab]	1.55 ± 0.07[c]	5.32 ± 0.10[a]	110.38 ± 0.70[a]
	Outlet 3	92.50 ± 0.02[a]	1.06 ± 0.03[b]	0.54 ± 0.00[c]	0.03 ± 0.00[b]	1.25 ± 0.07[d]	4.63 ± 0.12[a]	96.18 ± 1.37[a]
Day 7	Outlet 1	91.79 ± 0.66[a]	1.25 ± 0.10[a]	0.76 ± 0.00[a]	0.02 ± 0.00[b]	1.83 ± 0.04[b]	4.34 ± 0.86 [a]	94.55 ± 12.75[a]
	Outlet 2	91.68 ± 0.66[a]	1.13 ± 0.02[ab]	0.67 ± 0.01[b]	0.03 ± 0.01[ab]	1.75 ± 0.06[b]	4.74 ± 0.72[a]	99.41 ± 12.05[a]
	Outlet 3	91.51 ± 0.81[a]	1.25 ± 0.02[ab]	0.68 ± 0.00[ab]	0.04 ± 0.00[a]	2.05 ± 0.03[a]	4.47 ± 0.77[a]	96.18 ± 13.14[a]

[a,b,c] Values in a column without a common superscript are significantly different ($P<0.05$).
The values are given as means of triplicate determinations ± standard error.
**The values given are representative of the produce quality on arrival from the outlets

increased for produce from Outlet 3 by 33.33%. The observed changes can be attributed to the decrease in produce weight through transpiration losses. The proximate values observed in this study are comparable to most data found in literature (Weinberger *et al*., 2006; USDA, 2011). The results show that use of recommended temperature (0 ºC) does help maintain the original quality of cabbage for days in storage.

Socio-economic impacts of postharvest losses

Economic and environmental impact of cabbage postharvest losses

During the production and postharvest life cycle of cabbages, green house gasses (GHG) are emitted to the environment. Based on the research findings, the cabbage losses were estimated to contribute to 1.89 – 4.20 million t of $CO_{2\ eq.}$ (Table 6). To sink the average amount (2.94 million $CO_{2\ eq.}$) of these values at least 75 million trees would be required (at 0.039 t of $CO_{2\ eq.}$ per urban tree planted) (U.S. DOE, 1998). In addition to this, approximately 17.31 – 38.46 million MJ and 2.55 – 5.66 million m^3 of fossil energy and water footprint were also lost. These values equated to an average loss of 26.92 million MJ and 3.96 million m^3 of water foot print. The total water lost from the losses could sustain at least 139 726 – 310 136 individuals per day for a whole year, given that the standard daily water requirement for one person is 0.05 m^3 of water per day (Gleick & Iwra, 1996). The study showed that the severity of postharvest losses does not only contribute to poverty through lost food and income but also contributes to environmental and unsustainable usage of resources and the emission of unwarranted GHG gases that contribute to global warming.

Socio-economic impacts of postharvest losses

The value of cabbage losses at purchase ranged from R0.53 – 0.82 per kg. This meant for every one kg of whole cabbages purchased from the three retail outlets at least R0.68 was lost. The storage treatments had a significant ($P<0.05$) effect on overall revenue losses. Value of losses after 7 days of storage ranged from R0.43 – 0.82 per kg and R 0.76 – 1.30 per kg for cold and ambient stored produce respectively. National postharvest loss estimates were made based on the 2009 total volume (103 500 t) of fresh cabbages supplied to the domestic market (DAFF, 2011).

Table 6 Postharvest losses impact on energy used, GHG emissions and water foot print in the production of cabbage stored at ambient 22 - 25 ˚C; 52 - 55% RH) and optimum (0 ˚C; 91 - 97 % RH) over time

Source	Storage Condition		Estimated economic and physical losses			*Estimated environmental and resource impacts		
	Time (Days)	Temp (ºC)	Value (R/kg)	Physical (t x 10^3)	Value (ZAR x 10^6)	Emissions CO_2e (t x 10^6)	Energy Used (MJ x 10^6)	Water Foot Print (m^3 x 10^6)
Outlet 1	0**	-	0.82 ± 0.04^{cd}	34.96 ± 1.75^{d}	28.85 ± 2.80^{e}	4.20 ± 0.21^{d}	38.46 ± 1.92^{d}	5.66 ± 0.28^{d}
	3	0	0.66 ± 0.04^{f}	27.97 ± 1.75^{f}	18.52 ± 2.37^{f}	3.36 ± 0.21^{f}	30.77 ± 1.92^{f}	4.53 ± 0.28^{f}
		22 - 25	0.90 ± 0.05^{c}	38.46 ± 2.03^{c}	34.93 ± 3.66^{d}	4.62 ± 0.24^{c}	42.30 ± 2.23^{c}	6.23 ± 0.33^{c}
	7	0	0.82 ± 0.01^{cd}	34.97 ± 0.46^{d}	28.73 ± 0.76^{e}	4.20 ± 0.06^{d}	38.47 ± 0.51^{d}	5.66 ± 0.07^{d}
		22 - 25	1.27 ± 0.04^{a}	54.20 ± 1.75^{a}	69.13 ± 4.52^{a}	6.50 ± 0.21^{a}	59.62 ± 1.92^{a}	8.78 ± 0.28^{a}
Outlet 2	0**	-	0.53 ± 0.02^{g}	15.73 ± 0.61^{i}	8.35 ± 0.64^{hi}	1.89 ± 0.07^{i}	17.31 ± 0.67^{i}	2.55 ± 0.10^{i}
	3	0	0.53 ± 0.01^{g}	15.73 ± 0.36^{i}	8.33 ± 0.38^{hi}	1.89 ± 0.04^{i}	17.31 ± 0.40^{i}	2.55 ± 0.06^{i}
		22 - 25	1.06 ± 0.01^{b}	31.47 ± 0.34^{e}	33.31 ± 0.72^{de}	3.78 ± 0.04^{e}	34.61 ± 0.37^{e}	5.10 ± 0.05^{e}
	7	0	0.65 ± 0.02^{f}	19.23 ± 0.56^{h}	12.46 ± 0.73^{gh}	2.31 ± 0.07^{h}	21.16 ± 0.62^{h}	3.12 ± 0.09^{h}
		22 - 25	0.76 ± 0.02^{de}	22.73 ± 0.55^{g}	17.39 ± 0.85^{fg}	2.73 ± 0.07^{g}	25.00 ± 0.60^{g}	3.68 ± 0.09^{g}
Outlet 3	0**	-	0.70 ± 0.03^{ef}	22.73 ± 0.88^{g}	16.03 ± 1.22^{fg}	2.73 ± 0.11^{g}	25.00 ± 0.97^{g}	3.68 ± 0.14^{g}
	3	0	0.43 ± 0.04^{h}	13.99 ± 1.26^{i}	6.15 ± 1.05^{i}	1.68 ± 0.15^{i}	15.39 ± 1.39^{i}	2.27 ± 0.20^{i}
		22 - 25	1.14 ± 0.03^{b}	36.71 ± 0.85^{cd}	41.75 ± 1.91^{c}	4.41 ± 0.10^{cd}	40.39 ± 0.93^{cd}	5.95 ± 0.14^{cd}
	7	0	0.65 ± 0.00^{f}	20.98 ± 0.00^{gh}	13.62 ± 0.00^{fgh}	2.52 ± 0.00^{gh}	23.08 ± 0.00^{gh}	3.40 ± 0.00^{gh}
		22 - 25	1.30 ± 0.02^{a}	41.97 ± 0.80^{b}	54.52 ± 2.06^{b}	5.04 ± 0.10^{b}	46.16 ± 0.88^{b}	6.80 ± 0.13^{b}

^{a,b,c} Values in a column without a common superscript are significantly different (P<0.05).

*Estimated values obtained using the 2010 volume of cabbage sold by the NFPMs of 115 366 t

*The values given are representative of the produce quality on arrival from the outlets

In this study, cabbage postharvest losses were estimated to amounted to an annual loss of approximately 14 110 – 31 360 t valued at R7.49 – 25.89 million. This meant that at least 21 950 t of cabbage worth R15.92 million on average is lost annually at the national retail level. The study revealed that maintaining the optimum cold chain could prevent as much as 30% of the total losses observed in ambient stores after 7 days of storage.

Conclusions

Postharvest losses of cabbage at retail purchasing were 21.21% on average. The estimated volume of this loss is around 21 950 t valued at R15.92 million at the national level. Based on the average individual requirement of at least 2000 kcal (8374 kJ) per day (Story & Stang, 2005; Marcoe *et al.*, 2006; Maillot *et al.*, 2007), the total volume of these physical losses at national level could meet the daily dietary energy needs of at least 84 200 people for a whole month. In addition the cabbage lost could meet the daily vitamin C (75 - 90 mg/day) needs of at least 72 629 individuals for a whole year (Story & Stang, 2005; Marcoe *et al.*, 2006; Maillot *et al.*, 2007).

During post retail storage ascorbic acid content declined by 10.71% for optimally kept cabbages while those kept in room temperature had a decline of 40.81% after 7 days. Overall colour change, firmness decline and weight loss were also most pronounced for cabbages that were kept in ambient condition. The carotenoid, TSS, and TA did not show a common trend for all the cabbages. The incidence of mechanical damage is a major concern with regards to postharvest losses of cabbage at retail level and must be addressed. The appearance of cabbage stored at 22 - 25 ºC became objectionable in less than 3 days storage while it remained stable at 0 ºC.

The environmental impacts of these losses reveal that postharvest losses of cabbages contribute to the unwarranted emission of approximately 2.94 million t of CO_{2eq} green house gases. As much 26.92 million MJ (~7.48 million kWh) of fossil energy and 3.96 million m^3 of fresh water resources were also lost. The energy lost is worth R9.97 million given that the minimum Eskom tariff rate is R0.75 per kWh (Eskom, 2012). The fresh water lost could sustain at least 195 068 individuals daily for a whole year at a daily minimum rate of $0.05 m^3$ of water per day. Considering that at least 216 986 people stand to benefit from the wasted water annually it therefore means postharvest losses are causing a silent hunger which cannot simply go unnoticed.

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Chapter 5

POSTHARVEST LOSSES AND CHANGES IN QUALITY AND NUTRITIONAL VALUE OF CARROTS FROM RETAIL TO CONSUMER

Summary

Postharvest losses for carrots directly at purchasing from three retail outlets ranged from 13.72 – 22.11% with an average of 17.93%. Mechanical injury (87.88%) and root decay (12.12%) were the major causes of the losses. The losses differed for all three retail outlets at purchase and during consumer simulated storage. Carrot losses during consumer simulated storage were higher for produce kept at ambient temperature (22 - 25 ºC) compared to the recommended low storage temperature of 0 ºC. After 7 days losses ranged between 5.06 – 7.56% in low temperature storage and were 12.43 – 31.90% in ambient conditions. These losses after 14 days ranged from 8.56 – 12.67% and 20.33 – 69.75% for the different storage temperatures, respectively. Root weight loss after 14 days ranged from 0.84 – 1.19% in cold storage and was higher in ambient storage 6.89 – 8.75%. Colour change (ΔE) ranged from 3.51 – 5.52 and 3.64 – 9.28; firmness declined by 6.92 – 23.55% and 14.45 – 30.28% for cold and ambient stored carrots respectively. Ascorbic acid content declined by 12.03 – 39.81% only for carrots kept in ambient storage. Total carotenoid, TSS and TA contents all varied depending on the retail outlet as well as the storage temperature conditions. The proximate composition was also observed to change over time for some of the carrot produces. At national retail level, the estimated magnitude of these losses were equivalent to wastage of 15 250 t of fresh carrots valued at R21.71 million as well as 14.79 million MJ of energy and 3.74 million m^3 of fresh water. The water lost could meet the minimum daily requirements of at least 134 247 people for a whole year. Furthermore, the losses contribute approximately 1.37 million tonnes of unwarranted CO_{2eq} to the environment.

Introduction

Carrot (*Daucus carota* L.), a root vegetable, is indisputably one of the richest sources of β-carotene an essential nutrient for maintaining good eye sight and preventing night blindness (O'Neill *et al.*, 2001). When fresh, carrots have a crisp texture and are usually bright orange in colour, although purple, red, white, and yellow varieties exist (Vora, 2001). Carrots can be eaten as raw, cooked or processed through canning, freezing and dehydration. The carrot is also ranked among the top ten economically important vegetable crops in the world, with regards to production area and market value (DAFF, 2011). Vegetable production across the globe is increasing (Kader, 2005). This is correlated with growth in popular demand of health promoting foods and the advancement in agricultural technology. However not many can afford a vegetable rich diet because of economic constraints (Monde, 2003).

In South Africa carrot production is concentrated in the Western Cape, Gauteng, Free State, North West, Kwazulu Natal and Mpumalanga (DAFF, 2011). Carrots grow best under cool conditions and are thus mainly produced in winter. South Africa's carrot production was approximately 150 000 tonnes in 2009 with a gross value of around R380 million. Close to 3% of the national production was exported while another 12% went for processing. The major export markets for carrot are Mozambique (47%), Angola (12%) and the United Kingdom (10%), (DAFF, 2011).The ultimate destination for most (65%) of South Africa's domestic fresh carrot produce is the retail market.

The retail distribution is arguably the most important step of the entire postharvest system. It is here that consumer acceptance and rejection are determined (Shrewfelt & Prussia, 1993). As it is the only part of the postharvest process most consumers see, retail distribution provides an excellent opportunity to communicate with the consumer. Conditions within the retail outlet (temperature, relative humidity, and lightning), close display of compatible commodities, and general handling by store personnel and or consumers all affect fresh produce quality and acceptability (Nunes, 2009). Freshly harvested carrots have been found to undergo quality deterioration during storage as a result of three phenomena namely; microbial growth, physiological response to stress factors, and surface dehydration (Lavelli *et al.*, 2006). Losses at the retail and consumer levels are all governed by these common causes.

Storage of carrots at temperatures above 4ºC and low relative humidity (<90%) subjects the roots to weight loss stress (Lavelli *et al.*, 2006). Sensory changes during storage occur as a result of putrefaction by decay causing organisms such as *Erwinia*-, *Botrytis*- or *Sclerotinia*- species. Loss of taste and sweetness occurs as a result of a decrease in sugar content and formation of bitter off-flavours (Seliåsen *et al.*, 2004; Berger *et al.*, 2008). Root firmness declines as the level of water stress increases (Araya *et al.,* 2009). The most effective way to prevent quality losses at retail, aside from using low temperature storage, is a rapid turnover of stock on the shelves (Shrewfelt & Prussia, 1993).

Typical fresh vegetable losses range from 10 to 25 % (Shrewfelt & Prussia, 1993). It was earlier estimated that for developing countries, at least 5 % and as much as 100 % of a whole vegetable consignment could be lost between the field and the consumer (NAS, 1978; Coursey, 1983). Presently losses of up to 80% can occur if marketing is not properly organised (Ogang, 2011). In addition, the efficiency of delivering plant based foods to the consumer is coupled with significant environmental impacts, some of them related to climate change (Gonzàlez *et al.*, 2011). Postharvest losses of fresh produce are considered to be one of the major bottlenecks impacting on the potential volumes that could reach the market whilst contributing to unwarranted GHG emissions and resource waste.

Currently there limited information of postharvest loses of vegetables in South Africa and in particular of carrots as an entity. The available information on vegetable losses is mainly focused on individual groups rather than combined losses of the same vegetable regardless of cause (Kader, 2002). In the absence of reliable information, the country 's decision and policy makers may continue to advocate for the increase in carrot production without realising that the current volumes may be just sufficient if the level of postharvest losses was controlled (Kader, 2005). Without any idea of how great or small the losses are the country remains in the dark. It is of paramount importance that postharvest losses of vegetables be studied and understood so as to know their causes, their monetary value and most importantly their impact on the environment.

Therefore, the aim of this study was to evaluate the postharvest quality and incidence of losses of carrots at the retail level in South Africa. The specific objectives were to: (i) quantify the magnitude of tomato postharvest quantity losses from retail to consumer level, (ii) characterise the losses in sensory quality and nutritional value during storage, and (iii) estimate the environmental impacts of tomato postharvest losses.

Materials and methods

Sample material

Carrots of similar cultivar (Nantes type) were purchased from three different retail outlets (two supermarkets and one street market vendor) in Stellenbosch, South Africa. Produce from each retail outlet was then randomly divided into five equal batches of 15 kg each. One batch was analysed before storage, two batches were kept in room temperature storage (22 – 25 ˚C) and the other two were kept under optimum temperature storage (0 ˚C).The stored batches were analysed on days 7 and 14 respectively. On each day of analysis, carrots from each respective retail outlet were evaluated for external quality after which ~1.5 kg per outlet were cut, blended (AEG Electrolux, China) and stored into sealed 250ml plastic containers at -80 °C (Ultra-low temperature freezer, New Brunswick Scientific, England). The frozen samples were used for the analysis of the following parameters; total soluble sugar (°Brix), titratable acidity, ascorbic acid, total carotenoids. Freeze drying was conducted on samples used for proximate analysis.

Retail conditions

The conditions inside each retail outlet were determined using Tinytag Explorer temperature (-25 to 50°C) and relative humidity (0 to 100%) loggers (Gemini data loggers, UK). Carrot pulp temperature was measured inside each retail outlet using a FoodPro Plus temperature probe (Raytek Corporation, Santa Cruz, CA, USA) with a probe temperature range of -40 to 200ºC.

Postharvest loss assessment

External quality examination was carried out by visual inspection for insect damage, severe mechanical damage and decay from triplicate sub-groups (~5kg per batch) of each of the five batches from each Outlet. Severely cracked and broken carrot pieces together with those that had decay were all classified into losses. Presence of decay and cracks, compromise the safety of fresh vegetables especially if they are to be incorporated into raw dishes. Broken carrot pieces cause inconvenience during meal preparations as the tiny pieces are often difficult to peel and shape as desired. Economic loss was calculated by computing the monetary value of the physical loss, obtained by multiplying the percentage of physical loss with the actual selling price of each Outlet per kilogram of produce.

Weight loss

Carrots of uniform size and colour (3 x 1 kg packets per retail outlet) were randomly selected for each storage temperature condition. Weight change was monitored over a period of 14 days. The weight of each carrot was measured using a precision scale with an accuracy of ± 0.01g (Mettler Toledo scale Switzerland). Weight loss was determined by subtracting sample weight from their initial recorded weight and was presented as a percentage.

Colour

Triplicate colour measurements were taken on each carrot stick with a Chromameter CR-400 Konica Minolta (Sensing Inc, Japan) calibrated with a white standard tile (Y=94.00; *x*= 0.13141; *y*= 0.321). Colour output was expressed as L* (lightness), a* (green to red), b* (blue to yellow). Chroma values were calculated as $(a^{*2}+ b^{*2})^{1/2}$ and Hue angle as $\tan^{-1}$ (b*/a*). For each Outlet, 15 carrot sticks of uniform size and colour were randomly selected from each storage temperature condition (per retail outlet for evaluation). The colour measurements were taken over 14 days, on days 0, 7 and 14 respectively. The net colour difference, ΔE, was calculated as follows; $\Delta E^* = (\Delta L^{*2}+\Delta a^{*2} + \Delta b^{*2})^{1/2}$, (López *et al.*, 1998; García & Calixto, 2000).

Firmness

Destructive texture measurements were performed using a TA-XTPlus texture analyser (Stable Micro Systems, UK), with 15 replicates per Outlet treatment. Cutting was applied with a Warner Bratzler blade at a maximum force of 250 N. The sample was placed on the platform and measured with 250 N load cell at a deformation rate of 1 $mm.s^{-1}$. Cutting measurements were performed on the upper and lower end of the carrot stick and the peak force and their average was used to determine root firmness.

Chemical attributes

Total carotenoids

The total carotenoids were measured using a spectrophotometric method as by Opiyo and Ying (2005). Samples (1g) of chopped and then blended (Assistant all in one blender, AEG Electrolux, China) carrots were extracted by grinding in 14 mL solution of n-hexane: acetone (3:2 v/v). The homogenate was then centrifuged at 10 000 g for 10 min at 4 ºC in an Eppendorf centrifuge (Mark Chemicals, (Pty) Ltd, South Africa). The supernatant was topped up to a volume of 25 mL with the extraction solution. The absorbance was determined using a spectrophotometer (Helios Omega UV-Vis Thermo Scientific, USA). Pigment contents were calculated from the following equations:

$$\text{Total Carotenoids } (\mu g.g^{-1}) = = \frac{OD_{502} \text{ x } 4}{\text{Mass of Sample (g)}} \text{ X } 1000 \qquad 1$$

$$\text{Total Lycopene } (\mu g.g^{-1}) = \frac{OD_{502} \text{ x } 3.12}{\text{Mass of Sample (g)}} \text{ X } 1000 \qquad 2$$

Pigments were obtained as $\mu g.g^{-1}$ and later presented as mg/100 g of Fresh weight.

Ascorbic acid

Total ascorbic acid was content determined using the 2,6 dichloroindophenol (DCP) titration method under subdued light as according to AOAC (2006) method 967.21.

Total soluble solids (°Brix)

The total soluble solids (TSS) content was determined using a digital refractometer (Atago, Japan) calibrated at 23ºC

Titratable acidity

Expressed as percentage citric acid, was determined by titrating with 0.1N NaOH up to pH 8.1 using a TA- Metrohm 862 compact titrosampler (Metrohm, Switzerland).

Proximate composition

All components were determined using standard Analytical Official methods (AOAC, 2005) as follows: moisture (925.09), dietary fibre (993.21), protein (960.52), fat (920.85) and ash (923.03). A conversion factor (6.25) was used to determine the actual protein content of each sample by the Kjedahl method (N x 6.25).

Environmental Impact of postharvest losses

Green house gas emissions and total energy values for lost carrot produce were calculated using values provided in the study by Gonzàlez *et al.*, (2011) conducted in Sweden. The production of and transportation of carrots was reported to emit 0.09 kg CO_2 equivalents for every kg of produce while the energy consumed to produce this was 0.97 MJ. The water foot print was determined by multiplying the quantity of lost produce with the reference water foot print value of 245 m^3 per t provided by Mekonnen & Hoeskstra (2011).

Statistical analysis

Analysis of variance was performed using SAS version 9.1 (SAS Institute, 2006, Cary, USA). Significant differences between treatment means were assessed using Fisher's least significant-difference test. Variations were compared between retail outlets, storage conditions and over time. All values obtained are presented as means and their standard error.

Results and discussion

Carrot prices and characterisation of postharvest environment

The average selling price was R8.11 per kg and was least for the outdoor market carrots (Table 1). Relative humidity RH for the three retail Outlets ranged from 58.64 – 75.96% while the air temperatures ranged from 16.51 – 18.76 °C. The environmental conditions in the outdoor market (outlet 3) were significantly different ($P<0.05$) from those observed in the supermarkets. Retail Outlet 3 had the lowest RH and highest air and produce pulp temperatures, respectively. The conditions found in the outdoor market were the most unfavourable with regards to preserving shelf life as carrots keep best at 0 ºC and high RH >95% (Seliåsen *et al.*, 2004; Berger *et al.*, 2008).

Carrot quality

Quality assessment for the carrots was classified based on their appearance into good, decayed and mechanically damaged produce as presented in Fig. 1.

Postharvest losses

Total carrot losses at purchase ranged from 13.72 – 22.11% with an overall average

Table 1 Environmental conditions encountered in three retail outlets on purchase of carrots

Source	Retail Characterisation				
	Price (R.kg^{-1})	Air RH (%)	Air Temperature (ºC)	Produce Temperature (ºC)	Source Type
Outlet 1	9.00	75.96 ± 2.24^{a}	16.51 ± 0.06^{b}	6.80 ± 0.15^{b}	Supermarket
Outlet 2	9.33	69.50 ± 2.40^{a}	16.96 ± 0.05^{b}	6.20 ± 0.33^{b}	Supermarket
Outlet 3	6.00	58.64 ± 3.01^{b}	18.76 ± 0.10^{a}	9.04 ± 0.57^{a}	Outdoor market

^{a,b} Values in a column without a common superscript are significantly different (P<0.05).
*The values are given as means of triplicate determinations ± standard error.

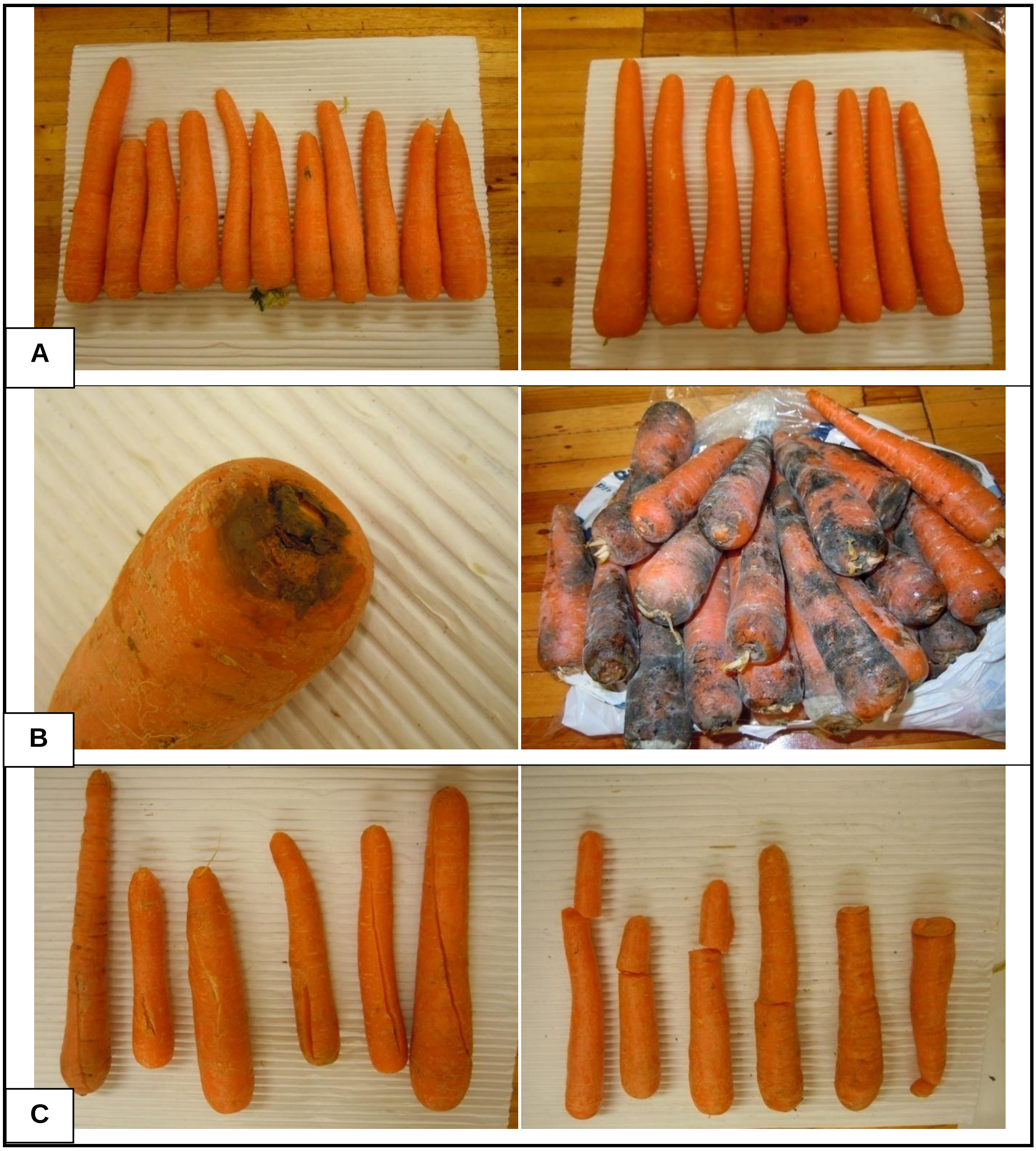

Figure 1 Photographs of representative carrot quality classified as (A) good, (B) decayed and (C) mechanically damaged carrots.

of 17.93 % (Table 2). The losses varied significantly ($P<0.05$) for all the retail outlets with highest values being observed for produce from retail outlet 3. Mechanical damage in the form of breakages (24.26%) and cracks (63.62%) and decay (12.12%) were the major contributing causes for loss. During post retail storage, produce losses were more subtle for carrot produce kept in cold store (0 ºC) produce compared to ambient (22 - 25 ºC) stored produce. After 7 days of storage losses ranged from 5.06 – 7.56% and 12.43 – 31.90% for cold and ambient stored produce respectively. At day 14, overall carrot losses were at 8.56 – 12.67% and 20.33 – 69.75% for produce kept in the cold and ambient temperatures respectively.

Produce from the supermarkets had the highest post retail storage losses compared to the outdoor market vendor after 14 days of ambient temperature storage. In addition, losses in ambient storage after 14 days were mostly due to decay 76.20 – 100% of the losses. Long term storage of carrot produce is important for conserving vegetable supplies all year round and use of low temperatures and high RH was found to be efficient in doing so (Kader, 2002). Shelf life of vegetables during storage as observed in previous studies is dependent on the initial quality, storage stability, the external conditions, and the handling methods (Shrewfelt & Prussia, 1993; Kader, 2002).

Weight Loss

The keeping quality of carrots is defined as the number of days the carrots remain at specified storage conditions before attaining the highest permissible moisture loss of 8% of the initial root weight (Robinson *et al.*, 1975; Caron *et al.*, 2003). Percentage weight losses ranged from 6.89 – 8.75% in ambient storage (Fig. 2) and 0.84 – 1.19% in cold store (Fig. 3) after 14 days, respectively. Physical weight loss in stored carrots occurs due to transpiration and has an effect on the produce's appearance by wrinkling and altering the texture of its skin (Caron *et al.*, 2003). Transpiration is caused by vapour pressure deficit (VPD), which results from the difference between the humidity of the surrounding air. Comparing the two storage regimes the cold store definitely offered the best storage conditions with regards to controlling weight loss.

Colour

The colour of carrots when purchasing is an important primary index in quality deter-

Table 2 Postharvest losses (%) of carrots from three retail outlets stored at ambient (22 – 25 ˚C; 56 - 59%RH) and optimum (0 ˚C; 9 4– 96 % RH) over time

Retail	Storage Condition		Overall Loss*	Causes contributing to loss		
	Duration (Days)	Temp ºC		Broken	Cracked	Decayed
Outlet 1	0	**	17.95 ± 0.91^{e}	12.11 ± 0.89^{efg}	66.82 ± 0.95^{b}	21.07 ± 1.32^{d}
	7	0	5.06 ± 0.53^{i}	14.86 ± 7.77^{def}	85.14 ± 7.77^{a}	0.00 ± 0.00^{f}
		22 – 25	31.90 ± 0.80^{c}	6.97 ± 0.67^{efg}	14.58 ± 0.61^{e}	78.45 ± 1.25^{b}
	14	0	8.56 ± 0.42^{hi}	45.99 ± 5.39^{b}	45.16 ± 3.74^{c}	8.86 ± 8.86^{ef}
		22 – 25	69.65 ± 0.40^{a}	0.00 ± 0.00^{g}	0.00 ± 0.00^{f}	100.00 ± 0.00^{a}
Outlet 2	0	**	13.72 ± 1.53^{f}	27.53 ± 0.30^{cd}	57.19 ± 7.36^{b}	15.28 ± 7.66^{e}
	7	0	6.43 ± 0.55^{i}	65.47 ± 4.07^{a}	34.53 ± 4.07^{d}	0.00 ± 0.00^{f}
		22 – 25	23.26 ± 2.18^{d}	7.84 ± 7.84^{efg}	13.56 ± 2.44^{e}	78.60 ± 6.87^{b}
	14	0	10.10 ± 0.13^{gh}	15.36 ± 2.74^{def}	37.44 ± 2.83^{cd}	47.20 ± 1.76^{c}
		22 – 25	41.51 ± 2.38^{b}	2.67 ± 2.67^{fg}	2.49 ± 0.14^{f}	94.84 ± 2.79^{a}
Outlet 3	0	**	22.11 ± 0.59^{d}	33.15 ± 1.00^{bc}	66.85 ± 1.00^{b}	0.00 ± 0.00^{f}
	7	0	7.56 ± 0.91^{hi}	17.67 ± 9.31^{de}	65.66 ± 4.35^{b}	16.67 ± 8.58^{e}
		22 – 25	12.43 ± 1.11^{fg}	30.89 ± 1.38^{c}	37.69 ± 0.99^{cd}	31.42 ± 2.31^{d}
	14	0	12.67 ± 1.01^{fg}	0.00 ± 0.00^{g}	23.80 ± 2.11^{e}	76.20 ± 2.11^{b}
		22 – 25	20.33 ± 1.88^{de}	5.67 ± 5.67^{efg}	20.12 ± 2.65^{e}	74.20 ± 3.09^{b}

^{a,b,c} Values in a column without a common superscript are significantly different (p<0.05).
The values are given as means of triplicate determinations ± standard error.
**The values given are representative of the produce quality before storage.

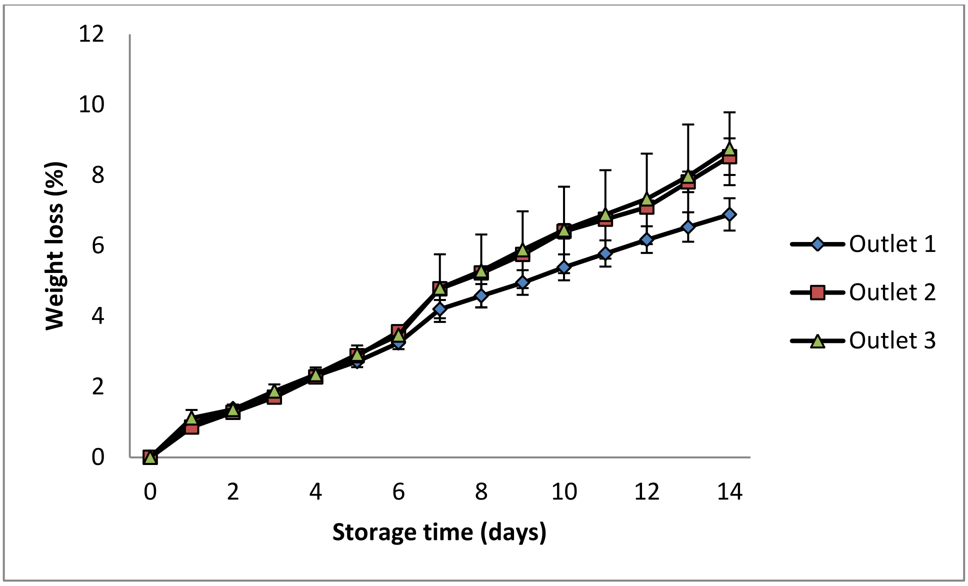

Figure 2 Percentage weight loss over time, of carrots from three different retailers stored at ambient temperature (22 - 25˚C; 56 -59% RH).

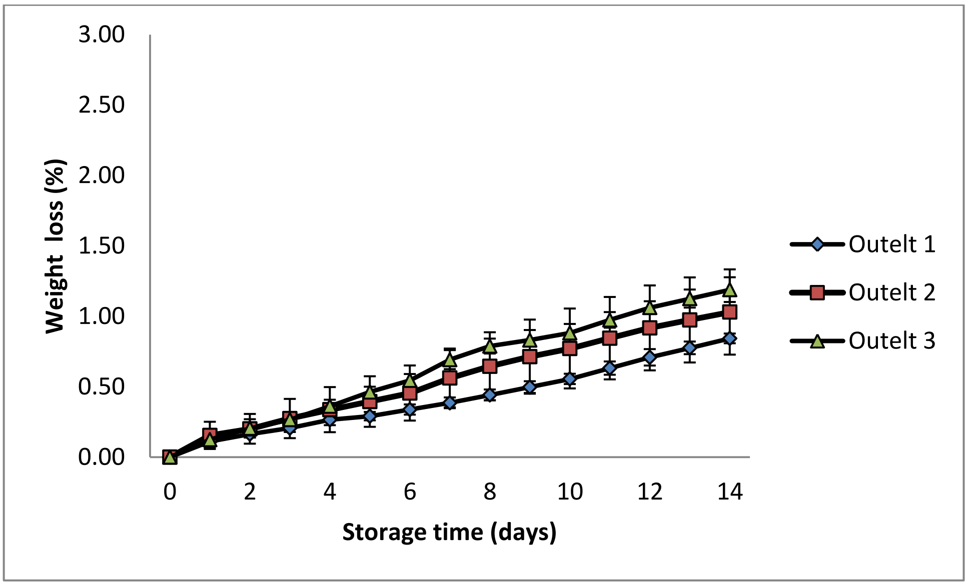

Figure 3 Percentage weight loss over time, of carrots from three different retailers stored at optimum temperature (0 - 0.5˚C; 94 – 95% RH).

-mination for both consumers and processors. Produce from retail Outlet 1 differed significantly ($P<0.05$) in orange colour having the highest a*, b* and chroma intensity C* values at purchase compared to the produce from retail outlets 2 and 3 (Table 3). There were no significant differences in produce colour between produce from retail outlets 2 and 3. However, changes in carrot colour during storage varied depending on the retail source and type of storage treatment. Produce from Outlet 1 showed a significant decline in orange colour which was characterised with significantly lower a*, b* and chroma (C*) values as well as a higher hue angle (Hº) after 14 days of storage while produce from retail Outlets 2 and 3 had negligible colour losses. Overall colour change (ΔE) was higher for ambient stored produce (3.51 – 5.52) compared to that kept in cold store (3.64 – 9.28).

Similar results were reported by Araya *et al.* (2009) who observed a significant decrease in chroma measurements for raw carrots after 7 and 14 days of storage, respectively. Produce kept in the cold store (0ºC) had significantly higher hue (Hº) values as compared to the ambient stored and therefore had better colour retention. Colour variation during storage between the Outlets was probably also affected by sprouting in the ambient store which started just after 7 days of storage. Gioppo *et al.* (2011) cited sprouting as one of the major causes for produce losses in tuber and root vegetables during storage. In their study approximately 50% of bulk stored carrots had sprouted while those in polyvinyl chloride (PVC) film-wrapped packaging showed 70% incidence of sprouting after 20 days of storage. Interestingly produce from the supermarkets also showed higher colour change (ΔE) in the cold store as compared to ambient store storage, while that from Outlet 3 had no significant difference in either temperature. After 14 days of storage carrots outlets 1 and 2 showed a higher significant ($P<0.05$) colour change compared to that kept in low temperature storage. This could probably be due to variation in initial colour of produce from the supermarkets and better colour retention in cold store. Carrots form outlet 3 did not show any significant difference in overall ΔE in either storage condition.

Firmness

Carrot quality is primarily determined by the overall firmness of the roots upon procurement. The firmness for the carrots from the three retail outlets ranged from 125.27 – 177.61 N and was highest for produce from Outlet 3 as shown in Table 3.

Table 3 Colour changes in carrots from three retail outlets stored at ambient (22 - 25 ˚C; 56 – 59%RH) and optimum (0 ˚C; 94 - 98 % RH) over time

Retail	Storage Condition		Colour Values						Firmness
	Time (Days)	Temp. (ºC)	L*	a*	b*	C*	H°	∆E	
Outlet 1	0	**	51.76 ± 0.38^{b}	21.21 ± 0.48^{a}	$33.40 \pm 0\ .48^{a}$	39.58 ± 0.63^{a}	57.62 ± 0.36^{f}	0.00 ± 0.00^{e}	155.72 ± 3.25^{c}
	7	0	50.46 ± 0.92^{cd}	17.77 ± 0.36^{cd}	29.16 ± 0.34^{bcd}	34.58 ± 0.44^{c}	59.09 ± 0.39^{g}	6.69 ± 0.81^{b}	138.31 ± 2.65^{d}
		22 – 25	49.25 ± 0.75^{cde}	18.53 ± 0.75^{cb}	29.16 ± 0.79^{cde}	34.57 ± 1.04^{c}	57.70 ± 0.50^{f}	7.48 ± 1.12^{ab}	118.32 ± 4.89^{fgh}
	14	0	48.50 ± 0.89^{de}	19.32 ± 0.47^{b}	$31.44 \pm .37^{ab}$	36.93 ± 0.51^{b}	58.48 ± 0.50^{def}	5.52 ± 0.84^{bc}	128.74 ± 6.67^{de}
		22 – 25	49.06 ± 0.88^{cde}	15.47 ± 0.52^{fg}	27.34 ± 0.51^{efg}	31.43 ± 0.67^{ef}	60.60 ± 0.50^{bc}	9.28 ± 0.90^{a}	105.45 ± 1.42^{fgh}
Outlet 2	0	**	49.25 ± 1.64^{cde}	15.34 ± 0.32^{fg}	26.71 ± 0.50^{fg}	30.82 ± 0.54^{ef}	60.11 ± 0.46^{bc}	0.00 ± 0.00^{e}	125.27 ± 1.64^{de}
	7	0	49.70 ± 1.16^{cde}	16.12 ± 0.49^{ef}	27.77 ± 0.50^{def}	32.12 ± 0.66^{ed}	59.94 ± 0.43^{bcd}	3.31 ± 0.45^{d}	118.89 ± 3.51^{ef}
		22 – 25	48.63 ± 194^{cde}	14.53 ± 0.47^{g}	25.63 ± 0.59^{g}	29.49 ± 0.68^{f}	60.48 ± 0.62^{bc}	3.37 ± 0.66^{d}	104.84 ± 1.22^{gh}
	14	0	53.63 ± 1.01^{ab}	15.93 ± 0.56^{efg}	27.42 ± 0.68^{efg}	31.73 ± 0.85^{def}	59.94 ± 0.47^{bcd}	3.51 ± 0.65^{d}	98.20 ± 5.88^{hi}
		22 – 25	55.38 ± 1.54^{a}	15.96 ± 0.58^{efg}	31.60 ± 1.67^{ab}	35.47 ± 1.66^{bc}	62.82 ± 0.96^{a}	6.68 ± 1.50^{b}	87.34 ± 2.53^{i}
Outlet 3	0	**	47.94 ± 0.88^{de}	15.72 ± 0.65^{fg}	26.90 ± 0.59^{fg}	31.19 ± 0.81^{ef}	59.84 ± 0.61^{cde}	0.00 ± 0.00^{e}	177.61 ± 3.48^{a}
	7	0	46.80 ± 1.11^{e}	16.62 ± 0.39^{def}	29.41 ± 0.49^{cd}	33.79 ± 0.59^{cd}	60.55 ± 0.35^{bc}	3.38 ± 0.50^{d}	169.88 ± 12.52^{bc}
		22 – 25	49.80 ± 0.95^{cde}	18.38 ± 0.58^{bc}	29.72 ± 0.55^{bcd}	34.96 ± 0.72^{bc}	58.34 ± 0.57^{cde}	3.38 ± 0.61^{d}	158.69 ± 5.22^{ef}
	14	0	50.57 ± 1.15^{bcd}	16.34 ± 0.53^{def}	30.22 ± 0.95^{bc}	34.41 ± 0.94^{c}	61.50 ± 0.84^{ab}	3.69 ± 0.97^{cd}	135.78 ± 1.92^{d}
		22 – 25	49.50 ± 0.84^{cde}	17.31 ± 0.57^{cde}	29.18 ± 0.52^{cde}	33.95 ± 0.70^{cd}	59.40 ± 0.57^{cde}	3.64 ± 2.65^{cd}	137.49 ± 3.93^{d}

^{a,b,c} Values in a column without a common superscript are significantly different ($P<0.05$).

*The values are given as means of triplicate determinations ± standard error.

**The values given are representative of the produce quality before storage.

The values obtained are in range with those reported by Opoku *et al*. (2009). They determined hardness of refrigerated raw carrots and obtained values ranging from 159.11 – 307.10 N. The cutting force action applied by a blade to the carrot stick can either indicate how resistant the tissue is to fracture (using the maximum force during cutting cycle) or how 'rubbery' the tissue is, as indicated by increase in both displacement and cutting force (Araya *et al.*, 2009). There was a general decrease in crisp texture of the carrots with increase in storage time. After 14 days of storage, losses in firmness ranged from 6.92 – 23.55% and 14.45 – 30.28% for cold store and ambient stored produce, respectively. Produce kept in cold store retained better firmness quality as compared to the wilted ambient stored produce.

Chemical attributes

Ascorbic acid

The ascorbic acid (vitamin C) content ranged from 1.21 – 1.51 $mg.100g^{-1}$ FW and was significantly ($P<0.05$) lowest for produce from the outdoor market (Table 4). Similar ascorbic acid values have been reported in literature (Vora, 2001; Opara & Al-Ani, 2010) who reported ascorbic acid concentrations of 0.60 – 1.21 and 1.40 – 2.20 $mg.100g^{-1}$ FW for freshly cut and whole raw carrots respectively. In this study, all the carrots kept in the cold store (0 °C) had better ascorbic acid retention with storage time while produce kept in ambient store showed a significant ($P<0.05$) decrease of 12.03 – 39.81% after 14 days. These results are comparable with those observed by Matéjková & Petříková (2010). They reported vitamin C losses of 47% in carrots stored for 30 days at 2 – 3 ºC. Ascorbic acid is believed to play a protective role in colour preservation through its antioxidant activities. Loss in ascorbic acid activity can be associated with the rapid darkening of carrot juice immediately after cutting the root (Vora, 2001).

Carotenoids

The total carotenoid content of the carrot samples from the three retail outlets were significantly ($P<0.05$) different on day 0, ranging from 86.97- 158.57 $mg.100g^{-1}$ fresh weight (FW) as presented in Table 4. Similar values were reported by Opara & Al-Ani (2010). They reported a total carotenoid content in fresh carrots of 119.15 $mg.100g^{-1}$ FW. During post retail storage, changes in carotenoid content varied significantly for all the retail sources. There was a general decline in carotenoid content especially for produce from Outlet 1, while that from Outlets 2 and 3 only showed a decline at day 3 for the cold store. After 14 days of post retail storage, a significant increase in carotenoid content was observed for cold stored produce from Outlet 3 while that from Outlet 2 did not show any significant ($P<0.05$) changes. Overall carotenoid losses carrots ranged between 8.17 – 11.46% and 5.65 – 41.92% for cold and ambient stored supermarket samples respectively. These values are comparable to those reported by Matéjková & Petříková, (2010).They reported an 11% decrease in total carotenoid concentration for carrots that had been kept for 30 days at 2.00 – 3.00 ºC.

Losses in carotenoid content were highest for produce from retail outlet 1 probably due to presence of mechanical injury (79.93%). Physical injury is one of the major causes contributing to loss of antioxidant components in fresh produce through the breakdown of cells and intracellular products and the release of oxidising enzymes (Allende *et al.*, 2006). Poon & Goldman (2002) reported that the decrease in total carotenoid concentration could also be due to the continued respiration by carrot roots in postharvest storage although the actual mechanism for degradation of carotenoids in carrot is not well understood. The decline in total carotenoid concentration in carrot roots during postharvest storage may be of importance to consumers and processors. Carrot roots are often stored for long periods of time before they are purchased or processed and this can have negative impact on the nutritive value of the carrot roots with time (Poon & Goldman, 2002).

The carotenoid concentrations were also observed to increase for some of the carrot produce during storage. Carotenoid increase can be ascribed to carotenoid synthesis in response to postharvest stress conditions (Lavelli *et al.*, 2006). Lavelli *et al.* (2006) also highlighted that changes in carrot carotenoids during storage are unpredictable as they observed an irregular trend in carotenoid changes in carrot produce over time. In their study, they did not observe any carotenoid degradation for carrots kept at 4 ºC and 10 ºC after 10 days of storage although there were significant ($P<0.05$) losses on days 3 and 7, respectively. From this study it can be seen that carrots are very sensitive to their storage environment which has an effect on overall their nutritional value.

Lycopene

Table 4 Chemical changes by carrots from three retail outlets stored at ambient (22 - 25 ˚C; 56 – 59%RH) and optimum (0 ˚C; 94 – 96 % RH) over time (100g^{-1}FW)

Retail	Storage Condition		Component					
	Time (Days)	Temp. ºC	Ascorbic acid (mg)	Carotenoids (mg)	Lycopene (mg)	TSS (%)	TA (%)	TSS/TA (%)
Outlet 1	0	**	1.51 ± 0.03^{a}	158.57 ± 6.26^{a}	25.33 ±0.17^{b}	8.53 ± 0.03^{b}	0.07 ± 0.00^{fg}	128.41 ± 6.52^{a}
	7	0	1.44 ± 0.04^{ab}	144.61 ± 0.86^{b}	26.35 ± 0.63^{a}	8.50 ± 0.06^{b}	0.08 ± 0.00^{de}	119.19 ± 5.11^{bc}
		22 – 25	1.08 ± 0.00^{d}	114.91 ± 2.91^{c}	21.06 ± 0.49^{cd}	8.23 ± 0.02^{c}	0.07 ± 0.00^{ef}	117.62 ± 0.24^{cde}
	14	0	1.52 ± 0.03^{a}	142.27 ± 4.73^{b}	25.38 ± 0.29^{b}	8.90 ± 0.03^{a}	0.09± 0.00^{b}	96.59 ± 3.04^{gf}
		22 – 25	1.08 ± 0.04^{d}	111.73 ± 3.01^{cd}	20.28 ± 0.16^{d}	7.73 ± 0.03^{e}	0.10 ± 0.00^{b}	80.19 ± 2.70^{ij}
Outlet 2	0	**	1.52 ± 0.04^{a}	86.97 ± 0.87^{ghi}	16.18 ±0.12^{f}	7.93 ± 0.07^{d}	0.08 ± 0.00^{cd}	95.46 ± 3.37^{fg}
	7	0	1.36 ± 0.07^{b}	74.16 ± 1.72^{j}	16.32 ± 0.15^{f}	8.00 ± 0.03^{d}	0.06 ± 0.00^{fg}	126.83± 5.98^{ab}
		22 – 25	1.10 ± 0.04^{d}	89.88 ± 2.74^{gh}	18.72 ± 0.05^{e}	7.93 ± 0.03^{d}	0.08 ± 0.00^{de}	103.87 ± 4.51^{def}
	14	0	1.36 ± 0.00^{b}	80.40 ± 1. 89^{ij}	15.18 ± 0.56^{g}	7.93 ± 0.03^{d}	0.07 ± 0.00^{ef}	113.33 ± 0.48^{cd}
		22 – 25	1.15 ± 0.02^{cd}	82.40 ± 0.31^{hi}	15.08 ± 0.28^{g}	7.63 ± 0.03^{e}	0.06 ± 0.00^{g}	127.22 ± 0.56^{ab}
Outlet 3	0	**	1.21 ± 0.08^{c}	94.61 ± 0.79^{fg}	16.54 ± 0.36^{f}	7.97 ± 0.03^{d}	0.11 ± 0.01^{a}	70.78± 4.11^{j}
	7	0	1.14 ± 0.00^{cd}	81.72 ± 4.38^{ij}	16.40 ± 0.23^{f}	7.10 ± 0.03^{f}	0.07 ± 0.00^{ef}	101.43 ± 0.41^{ef}
		22 – 25	1.17 ± 0.04^{cd}	104.91 ± 0.58^{de}	19.20 ± 0.06^{e}	8.20 ± 0.00^{c}	0.10 ± 0.00^{b}	85.04 ± 3.04^{hi}
	14	0	1.22 ± 0.05^{c}	119.73 ± 1.57^{c}	21.94 ± 0.44^{c}	8.20 ± 0.06^{c}	0.09 ± 0.00^{bc}	91.11 ± 0.64^{gh}
		22 – 25	1.08 ± 0.03^{d}	100.33 ± 1.14^{ef}	16.33 ± 0.13^{f}	8.30 ± 0.06^{c}	0.11± 0.00^{a}	73.38 ± 2.54^{j}

[a,b,c] Values in a column without a common superscript are significantly different (P<0.05).

*The values are given as means of triplicate determinations ± standard error.

**The values given are representative of the produce quality before storage.

The lycopene content a major carotenoid component was observed to follow a similar trend as that of the total carotenoids (Table 4). The average lycopene content for the carrots on the day of purchasing ranged from 16.18 – 25.33 mg.100g^{-1} FW. Losses in lycopene content were only significant ($P<0.05$) ranging from 7.29 – 24.90% for ambient stored produce from the supermarkets after 14 days of storage. There were no significant changes in produce kept in cold store except for produce from outlet 3 that with a 32.65 % increase in lycopene content.

Total soluble solids (TSS)

The total soluble solids (TSS) ranged from 7.97 – 8.53 % (Table 4). Opoku *et al.*, (2009) reported similar values for carrot produce ranging from 8.30 – 9.40 ºBrix while Vora, (2001) reported values ranging from 7.6 – 9.8 ºBrix. Produce from retail outlets 1 and 3 showed a significant increase (2.89 – 4.34%) in TSS while that from outlet 2 did not show any significant changes in cold store after 14 days of storage. The TSS values were observed to decline (3.78 – 9.38%) for room stored produce from the supermarkets while produce from the outdoor retailer showed a 4.14% increase after 14 days of storage. The TSS is one of the primary parameters used to assess carrot juice quality. Sugars represent the major components of TSS with both reducing and non reducing sugars such as sucrose, maltose and glucose that all provide sweetness (Vora, 2001). The commercially acceptable TSS reference value for carrot juice is of 8.00 ºBrix (Vora, 2001). Therefore all the carrot produce in this study was commercially acceptable on the day of purchase.

Titratable acidity (TA)

Carrots are regarded to be typically low in acid (Vora, 2001). Commercially the TA value is equally as important as TSS with regards to quality scoring. The TA (citric acid) values ranged from 0.07 – 0.11% on day 0 (Table, 4). These values are comparable to those reported by Vora (2001), who in their study determined acidity values in the range of 0.06 – 0.09%. Acidity reference values of 0.06% are commonly applied in industry (Vora, 2001). Changes in TA content during storage differed significantly ($P<0.05$) for all the carrots depending on the retail source and type of storage treatment. Produce from Outlet 1 showed an increase in TA with increase in storage time. Produce from Outlet 2 showed a general decrease with storage time which was more pronounced in cold store. Produce from Outlet 3 showed a decline TA in for produce kept in cold store while in ambient store the values remained significantly unchanged.

TSS/TA Ratio

The ratio of sugar: acid ratio varied widely between the carrot produces from the three retail outlets as well as during storage (Table 4). On day 0 the values ranged from 70.78 – 128.41% and were lowest for produce from the supermarkets. A combination of high TSS levels and low acidity increases the sugar: acid ratio which in turn has a positive impact on the taste of the product. The TSS/TA ratio was observed to decline for produce from outlet 1 while produce from Outlet 2 showed an increase. Produce from Outlet 3 only increased for cold stored carrots but remained significantly unchanged in ambient store.

Proximate composition

Table 5 shows a summary of the proximate results of the carrots during storage. The average moisture content was 89 $g.100g^{-1}$ FW. The proximate values obtained in this study for dietary fibre (2.04 -2.3 $g.100g^{-1}$ FW) and proteins (1.11 -1.20 g.100g-1 FW) are comparable to those reported by Vora (2001). Crude fibre for fresh carrots was observed to range between 1.90 – 2.23 g per 100g FW while the protein values ranged from 1.10 – 1.19 $g.100g^{-1}$ FW. Changes in moisture content during postharvest storage probably contributed to the variation in overall proximate composition after 14 days of cold storage. There was a significant increase in total ash (11.72 – 17.56 %) for produce from Outlets 1 and 3, while there was no significant change for Outlet 2 in ash content. Significant increases were observed for total carbohydrate (22.12 – 36.05 %) and energy (18.96 – 30.56 %) for all the outlets at day 14. Only produce from Outlet 1 had a significant increase in total dietary fibre (30.73%).

Socio-economic impacts of postharvest losses

The monetary value of carrot losses at purchase ranged from R1.28 – 1.62 per kg. This meant that for every one kg of carrots purchased from the three retail outlets approximately R1.41 was lost. After 14 days of post retail storage, the average monetary losses ranged from R1.22 – 6.27 per kg and R0.76 – 0.94 per kg for ambient and cold stored carrots, respectively. Based on the percentage losses of the

Table 5 Proximate composition changes of retail carrots stored in optimum temperature (0 - 0.5 ˚C; 94 - 98% RH) over time (per $100g^{-1}$ FW)

Source*		Component						
		Moisture	**Protein**	**Ash**	**Fat**	**D. Fibre**	**Carbohydrate**	**Energy (kJ)**
Day 0**	Outlet 1	89.35 ± 0.09^{bc}	0.51 ± 0.00^{d}	0.67 ± 0.00^{c}	0.09 ± 0.01^{a}	2.39 ± 0.08^{b}	6.96 ± 0.18^{a}	128.38 ± 3.60^{ab}
	Outlet 2	89.72 ± 0.01^{ab}	0.63 ± 0.02^{c}	0.67 ± 0.01^{c}	0.06 ± 0.02^{ab}	2.04 ± 0.09^{c}	6.88 ± 0.16^{a}	128.02 ± 0.70^{a}
	Outlet 3	89.96 ± 0.12^{a}	0.70 ± 0.01^{b}	0.77 ± 0.02^{b}	0.07 ± 0.02^{ab}	2.40 ± 0.10^{b}	6.15 ± 0.05^{b}	117.37 ± 1.34^{b}
Day 14	Outlet 1	88.87 ± 0.20^{d}	0.63 ± 0.02^{c}	0.79 ± 0.01^{b}	0.06 ± 0.00^{ab}	3.13 ± 0.09^{a}	6.62 ± 0.21^{ab}	123.75 ± 3.45^{ab}
	Outlet 2	89.73 ± 0.07^{ab}	0.53 ± 0.00^{d}	0.65 ± 0.01^{c}	0.04 ± 0.00^{b}	2.01 ± 0.02^{c}	7.00 ± 0.06^{a}	127.66 ± 1.23^{ab}
	Outlet 3	89.14 ± 0.27^{cd}	0.76 ± 0.02^{a}	0.86 ± 0.00^{a}	0.07 ± 0.01^{ab}	2.47 ± 0.03^{b}	6.88 ± 0.40^{ab}	130.60 ± 5.49^{a}

[a,b,c] Values in a column without a common superscript are significantly different (P<0.05).
*The values are given as means of triplicate determinations ± standard error.
**The values given are representative of the produce quality before storage.

Table 6 Postharvest losses impact on energy used, GHG emissions and water foot print in the production of carrots stored at ambient (22 – 25 ˚C; 56 – 59%RH) and optimum (0 ˚C; 94 – 96 % RH) over time

Retail	Storage Condition		Estimated economic and physical losses			*Estimated environmental and resource impacts		
	Time (Days)	Temp (ºC)	Value (R/kg)	Physical (t x 10^3)	Value (ZAR x 10^6)	Emissions CO_2e (t x 10^6)	Energy Used (MJ x 10^6)	Water Foot Print (m^3 x 10^6)
Outlet 1	0	**	1.62 ± 0.08^{e}	15.27 ± 0.77^{e}	24.81 ± 2.44^{e}	1.37 ± 0.07^{e}	14.81 ± 0.75^{e}	3.74 ± 0.19^{e}
	7	0	0.46 ± 0.05^{j}	4.30 ± 0.45^{i}	2.00 ± 0.39^{g}	0.39 ± 0.04^{i}	4.17 ± 0.44^{i}	1.05 ± 0.11^{i}
		22 – 25	2.87 ± 0.07^{c}	27.14 ± 0.68^{c}	78.03 ± 3.88^{c}	2.44 ± 0.06^{c}	26.33 ± 0.66^{c}	6.65 ± 0.17^{c}
	14	0	0.77 ± 0.04^{hi}	7.28 ± 0.36^{hi}	5.64 ± 0.57^{g}	0.70 ± 0.03^{hi}	7.07 ± 0.35^{hi}	1.78 ± 0.09^{hi}
		22 – 25	6.27 ± 0.04^{a}	59.27 ± 0.34^{a}	371.58 ± 4.26^{a}	5.33 ± 0.03^{a}	57.49 ± 0.33^{a}	14.52 ± 0.08^{a}
Outlet 2	0	**	1.28 ± 0.14^{f}	11.67 ± 1.30^{f}	15.32 ± 3.14^{efg}	1.05 ± 0.12^{f}	11.32 ± 1.26^{f}	2.86 ± 0.32^{f}
	7	0	0.60 ± 0.05^{ij}	5.47 ± 0.47^{i}	3.33 ± 0.54^{g}	0.49± 0.04^{i}	5.30 ± 0.46^{i}	1.34 ± 0.12^{i}
		22 – 25	2.17 ± 0.20^{d}	19.79 ± 1.86^{d}	43.70 ± 8.25^{d}	1.78 ± 0.17^{d}	19.19 ± 1.80^{d}	4.85 ± 0.46^{d}
	14	0	0.94 ± 0.01^{gh}	8.59 ± 0.11^{gh}	8.10 ± 0.21^{fg}	0.77 ± 0.01^{gh}	8.34 ± 0.11^{gh}	2.11 ± 0.03^{gh}
		22 – 25	3.87 ± 0.22^{b}	35.32 ± 2.03^{b}	137.70 ± 15.31^{b}	3.18 ± 0.18^{b}	34.26 ± 1.97^{b}	8.65 ± 0.50^{b}
Outlet 3	0	**	1.33 ± 0.04^{ef}	18.81± 0.50^{d}	24.99 ± 1.32^{e}	1.69 ± 0.05^{d}	18.25 ± 0.49^{d}	4.61 ± 0.12^{d}
	7	0	0.45 ± 0.05^{j}	6.43 ± 0.77^{hi}	3.00 ± 0.74^{g}	0.58 ± 0.07^{hi}	6.24 ± 0.75^{hi}	1.58 ± 0.19^{hi}
		22 – 25	0.73 ± 0.07^{hij}	10.57 ± 0. 94^{fg}	8.01± 1.36^{fg}	0.95 ± 0.08^{fg}	10.26 ± 0.92^{fg}	2.59± 0.23^{fg}
	14	0	0.76 ± 0.06^{hi}	10.78 ± 0.86^{fg}	8.30± 1.33^{fg}	0.97 ± 0.08^{fg}	10.46 ± 0.84^{fg}	2.64 ± 0.21^{fg}
		22 – 25	1.22 ± 0.11^{fg}	17.30 ± 1.60^{de}	21.47 ± 3.88^{ef}	1.56 ± 0.14^{de}	16.79 ± 1.55^{de}	4.24 ± 0.39^{de}

^{a,b,c} Values in a column without a common superscript are significantly different (P<0.05).

*Estimated values obtained using the 2010 volume of carrots sold by the NFPMs of 85 062 000 kg

*The values given are representative of the produce quality on arrival from the outlets carrots before post retail storage, estimates were made to determine the potential volume of carrots that could be lost at the national retail level of South Africa. At national level these values translated into an estimated annual loss of 12 540 – 20 200 t valued at R16.45 – 26.84 million (Table 6).Therefore at least 16 380 t of carrots worth R23.31 million is lost annually. These estimations were obtained based on the 2009 domestic supply volume of 91 369 t.

The environmental impacts of these losses also at the national retail level were found to contribute to the emission of unwarranted 1.13 – 1.82 million t $CO_{2\ eq.}$ Gases. To sink the average amount (1.48 million t of $CO_{2eq.}$) it would require the planting of at least 38 million trees (at 0.039 t CO_2 per urban tree planted) (U.S. DOE, 1998). The GHG and environmental inventory process in South Africa continues to face a number of challenges, the most significant of which is the availability of activity data for computation of the emissions. This requires spatial data, in-depth research and modelling studies in order to create a robust data base for land use and land use changes (DEAT, 2009). Therefore the data used in this research was based on limited estimates by international sources (Gonzàlez *et al.*, 2011; Mekonnen & Hoekstra, 2011). The findings from this study have revealed that postharvest losses of carrots are accompanied by significant annual emissions together with wastage of energy and water resources.

Furthermore, an estimated 12.16 – 19.60million MJ of fossil energy and 2.45 – 3.94 million m^3 of the water foot print were also lost. On average this estimates to t 15.89 million MJ and 3.20 million m^3 of fossil energy and water loss. The water foot print is an indicator of direct and indirect appropriation of fresh water resources (Mekonnen & Hoekstra, 2011). Currently agriculture accounts for more than 71% of global blue water consumption and is the major contributor to global fresh water withdrawal which has increased by 7 fold in this past century (Marien, 2011). This therefore means that for every kg of fresh produce production an equivalent percentage of that water is wasted for each unit of postharvest losses. The total water lost could sustain at least 134 247 – 175 342 individuals daily for a whole year lives given that the basic water requirement standard to sustain one individual per day is 0.05 m^3 of water (Gleick & Iwra, 1996).

Conclusions

The problem of postharvest losses of carrots in the South African retail outlets is mainly due to mechanical damage of the produce before it reaches the display. Mec-

-hanical injury can be induced by rough handling of produce, use of improper packaging and inappropriate harvesting methods. At least 17.93% of the total carrot production is destined for postharvest losses. The estimated volume of this loss is around 16 380 t valued at R23.31 million at the national level. Mechanical injury was identified as one of the major causes for the losses therefore the next step would be to trace exactly where along the chain this is occurring and putting control measures. Based on the average individual requirement of at least 2000 kcal (8374 kJ) per day (Story & Stang, 2005; Marcoe *et al.*, 2006; Maillot *et al.*, 2007), the total physical losses on day 0 could meet the daily dietary energy needs of at least 78 614 people for a whole month. In addition the carrots lost could meet the daily carotenoid needs of at least 8.48 – 16.96 million individuals for a whole month based on the findings by the IOM (2001). They determined that consumption of at least 3 - 6 mg of beta carotene daily (equivalent to 833 – 1 667 IU vitamin A) of vitamin E per day will maintain blood levels of beta-carotene in the range associated with a lower risk of chronic diseases (Office of Dietary Supplements, 2006).

During post retail storage ascorbic acid content declined by 6.98% for optimally kept tomatoes while those kept in room temperature had a decline of 19.80% after 7 days. The losses in ascorbic acid content were significant mostly for produce kept in ambient room temperature conditions. Overall colour change, firmness decline and weight loss were also most pronounced for carrots that were kept in room temperature. The carotenoid, TSS, and TA did not show a common trend for all the carrots. The environmental impacts of these losses reveal that postharvest losses of carrots contribute to the unwarranted emission of approximately 1.48 million t of CO_{2eq} green house gases. As much 15.89 million MJ (~4.42 million kWh) of fossil energy and 3.2 million m^3 of fresh water resources were also lost. The energy lost is worth R5.86 million given that the minimum Eskom tariff rate is R0.75 per kWh (Eskom, 2012). The fresh water lost could sustain at least 175 342 individuals daily for a whole year at a daily minimum rate of $0.05m^3$ of water per day.

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Chapter 6

GENERAL DISCUSSION AND CONCLUSIONS

Vegetables are an important component of daily diets across the world as they are central to most nutrition, food security and poverty reduction (Keatinge *et al*., 2011). Diets deprived of vegetables are often rich in carbohydrates contributing to a high rise of obesity related problems and other malnutrition disorders (Monde, 2003; Vorster, 2010). One of the main challenges to providing the consumer with fresh vegetables is that they are subject to rapid quality deterioration in terms of both appearance and chemical attributes (Nunes *et al.*, 2009; Kader, 2010; FAO, 2011). This quality deterioration can be a result of high moisture content coupled with ongoing metabolic activities, presence of spoilage pathogens, and insect pests (Nunes, 2008; Babita & Kiranmayi, 2010). Furthermore, vegetables often reach the retail markets at least one or two days after harvest thus, the chances of the quality deteriorating are greater (Nunes, 2008; Babita & Kiranmayi, 2010).

Postharvest vegetable losses at the retail and consumer levels represent significant amounts of capital and resource waste (Ventour, 2008; Nunes *et al.*, 2009; Parfitt *et al*., 2010). This includes water, labour and energy invested in their production and marketing (Buzby *et al*., 2011). The causes of vegetable losses vary throughout the world and are unique to each specific condition and local situation (Kader, 2005; FAO, 2011; Kader, 2010). However, there is limited data on global vegetable losses with regards to the magnitude, exact causes and monetary values of the losses at the different points of the postharvest supply chain (Parfitt *et al*., 2010). A comprehensive study on vegetable losses would therefore require quantifying the losses both in terms of financial and nutritional terms (Weinberger *et al*., 2008). Data obtained can be used to estimate the impacts of the losses at local, national and regional level.

The average retail prices per kg of the vegetables used this study were (R9.67) for tomato, R8.11 for carrot and R3.39 for cabbage. As expected, vegetables from the supermarkets (Outlets 1 and 2) were comparatively more expensive to that from the Outdoor market (Outlet 3). Mechanical injury and decay were the major visual attributes for poor quality before and after post retail storage. Vegetables from Outlet 3 had the least amount of decay compared to produce from the supermarkets. Vegetable losses at retail purchasing were highest for cabbage (21.21%), followed by carrot (17.93%) and tomato (14.56%), respectively. Tomato losses had the highest economic value of R1.53 per kg followed by carrot (R1.41) and cabbage (R0.53), respectively. The magnitude of vegetable losses at retail observed fall in the range with those (5 – 79%) reported by Kitinoja (2010) in four different developing countries. Tomato was the only vegetable commonly grown in all four countries studied by Kitinoja (2010) and the losses ranged from 12.5 – 31.2 %.

Retail and consumer simulated storage conditions had a significant ($P<0.05$) effect on the overall quality of vegetables. The environmental conditions were cooler and significantly more humid at the supermarkets compared to the outdoor market based on the data from the temperature and humidity loggers. Throughout the study, the storage conditions for Outlet 3 were the least favourable as compared to those found in the supermarkets. However, none of the outlets kept their produce at the recommended optimum temperature and relative humidity. This was probably due to financial restraints (Nunes, 2008).

Temperatures below 15 ºC have been found to delay changes of vegetable quality attributes during storage (Nunes *et al*., 2009). The use of ambient temperature (22 – 25 ºC) promotes ripening especially for fruit vegetables such as the tomatoes which are often harvested prematurely ripe (Kader, 2002; Nunes, 2008). However, ambient storage temperature has the most negative effect on leafy vegetables like cabbage (Nunes, 2008). The accelerated physical weight losses and colour changes render the leafy vegetables unmarketable unless the outer leaves are regularly trimmed (Buzby *et al*., 2011).

The recommended storage temperatures used for the study were 10 – 12.5 ºC for tomato, 0 ºC for cabbage and carrot (Kader, 2002; Nunes, 2008). Storage losses for tomato and cabbage were 18.52% and 16.67% after 3 days. Carrot losses were lower at 11.83% after 7 days with all respective cold temperature storage temperatures. Ambient storage losses for carrot were also the lowest for the three vegetables at 22.53% after 7 days while tomato losses stood at 24.27%, cabbage at 34.34% after 3 days. The higher ambient temperature always compromised quality of the vegetables over time.

Low temperature storage was observed to delay the rate of moisture loss by at least 3 times that observed at ambient storage for all three vegetables. In general vegetables from Outlet 3 especially, had the highest weight loss rate of the three outlets. Vegetable weight losses in the respective low temperature conditions were 1.11% for tomato, 4.51% for cabbage and 0.54% for carrot after 7 days. Weight losses in ambient temperature were 4.65% for tomato and 13.03% for cabbage after 7days. Carrots proved to retain weight better, and were therefore kept in both storage conditions for an additional 7 days. Overall weight loss by the carrots after 14 days was 1.02% and 8.06% for low and ambient temperature storage, respectively. In all storage treatments cabbage (leafy vegetable) was the most affected with regards to weight loss while carrot (root vegetable) was the most shelf stable.

Colour change (ΔE), firmness and ascorbic acid content losses were more pronounced in ambient storage conditions than in cold store. Carrots had the least ascorbic acid losses in either storage treatment. After 7 days of storage ascorbic acid losses for all three vegetables ranged from 6.98 – 12.62% and 19.80 – 40.81% for produce kept in low temperature storage and ambient storage conditions, respectively. The TSS, TA, TSS/TA and total carotenoid content varied depending on the retail source and vegetable type hence there was no common trend for all vegetables over time. A more accurate conclusion could be derived at probably if the produce had been traced from their point of harvest. This would provide the postharvest handling history of the vegetables, maturity stage at harvesting and also help explain the inherent quality changes observed over time (Kader, 2002). Table 1 summarises the major quality losses commonly observed for all three vegetables after 7 days only. The proximate composition of the vegetables did not change much over time although ash, fat and dietary fibre components were observed to increase for carrots and cabbage.

The use of postharvest percentage losses alone can be misleading (Kitinoja, 2010). Knowing the actual volumes produced and marketed allows one to quantify the tonnage lost (Weinberger *et al.*, 2008; Parfitt *et al.*, 2010). The significance of this is that one is able to understand the difference between vegetables with high percentage losses from those with high volume losses (Kitinoja, 2010). This can be achieved looking at individual vegetable losses; their retail prices and total production volumes as opposed to focusing on combined vegetable data (Weinberger *et al.*, 2008). Vegetable losses obtained by this research were also projected to the annual national vegetable supply. The statistics were from the 2010 – 2011 season and only included vegetables destined for the domestic market via the National Fresh Produce Markets (NFPMs). Tomato production (550 000 t) in the year 2010 was more than double that for cabbage (154 000 t) and carrot (140 000 t), respectively (DAFF, 2011abc). Therefore, the volume of tomatoes (251 261 t) that went to the domestic markets was higher than that for cabbage and carrot, respectively. The economic

Table 1 Major quality changes (%) for tomato, cabbage and carrot after 7 days of storage in different temperatures

Vegetable	Temperature (ºC)	Weight loss	Firmness loss	Colour (∆E)	Ascorbic acid loss
Tomato	10 –12.5	**1.11** (0.70 – 1.84)	**19.58** (15.63 – 23.37)	**5.88** (3.54 – 7.86)	**12.62** (10.65 – 15.46)
	22 – 25	**4.65**(3.41 – 7.06)	**53.40** (46.44 – 63.09)	**6.10** (3.88 – 8.01)	**39.70** (33.61 – 44.20)
Cabbage	0	**4.51** (3.83 – 5.60)	**10.75** (6.83 – 14.20)	**10.70** (10.40 – 11.27)	**10.71** (8.69 – 15.54)
	22 – 25	**13.03**(11.65 – 13.83)	**20.09** (14.12 – 28.73)	**16.45** (14.48 – 20.19)	**40.81** (20.54 – 66.02)
Carrot	0	**0.55** (0.38 – 0.69)	**6.88** (4.35 – 11.18)	**4.46** (3.31– 6.69)	**6.98** (4.64 – 10.53)
	22 – 25	**1.53** (1.40 – 1.60)	**16.99** (10.65 – 24.02)	**4.74** (3.37 – 7.48)	**19.80** (3.31 – 28.48)

Bolded values represent **mean** for all three retail outlets, the brackets provide the minimum and maximum values of the mean value of the losses would be around R61.64 million, R17.74 million and R21.71 million for the three vegetables accordingly. Postharvest losses have an impact on food and nutritional security. This is because the inherent nutritional content of vegetables is lost with each physical discard. The estimated volume of tomato produce lost (37 200 t) could meet the daily ascorbic acid requirement of at least 255 000 (~1.15 times the size of Stellenbosch population) individuals for a whole month (Stellenbosch Municipality, 2011).This is given that an adult individual requires at least 40mg of ascorbic acid per day (Gupta & Bains, 2006).

According to the IOM (2001) consumption of at least 3 - 6 mg of beta carotene daily (equivalent to 833 – 1 667 IU vitamin A) is important for a healthy diet free of many chronic diseases (Office of Dietary Supplements, 2006). Therefore the carrot produce lost (15 250 t) could meet the carotenoid needs of at least 10.44 million individuals for a whole year. Based on the average individual requirement of at least 2000 kcal (8374 kJ) per day (Story & Stang, 2005), the total physical losses for day 0 could meet the daily dietary energy needs of at least 62 162 – 151 202 people for a whole year. This is important especially for people who solely rely on vegetables for their food.

Postharvest losses contribute to unwarranted green house gas emissions (GHGE). The amount of carbon dioxide equivalents (CO_{2eq}) produced varies for all vegetables during their life cycles (González *et al*., 2011). At least 370 g.kg^{-1} of CO_{2eq} is emitted during the lifecycle of tomatoes while cabbage and carrot produce only 120 g and 90 g respectively (González *et al*., 2011). Accordingly, postharvest tomato losses contribute 13.77 million t of CO_{2eq} which is at least five to nine times more that for cabbage (2.94 million t of CO_{2eq}) and carrot (1.37 million t of CO_{2eq}) respectively. To sink these volumes of CO_2 it would require the planting of at least 155 million trees (at 0.039 t CO_2 per urban tree planted) (U.S. DOE, 1998). Therefore postharvest losses set back all efforts aimed at protecting the environment. For that reason, reduction of postharvest vegetable losses can be a complementary measure to planting of more trees. Table 2 summarises the production data, physical losses as well as the environmental and resource impacts, of postharvest vegetable losses.

In terms of GHGE production postharvest losses of tomatoes are more severe per unit kg. Carrots on the other hand carry the highest water foot print impact per kg unit of production.

Water and energy resources are also wasted with the losses (Table 2). According to literature findings, water requirements for production and distribution of

Table 2 Summary of vegetable production and market supplies, retail prices, nutritional values, postharvest losses and impacts of the losses.

Parameter	Tomato	Cabbage	Carrot
Production and Marketing			
Production (t)*	540 000	138 000	150 000
Fresh market supply (t)*	251 261	103 500	91 369
Price (ZAR/kg)	**9.67** (9.00 – 11.00)	**3.39** (2.71 – 3.88)	**8.11** (6.00 – 9.33)
Key nutritional value			
Ascorbic acid mg.100_g^{-1}	**10.96** (9.7 – 12.47)	**6.21** (5.13 – 7.63)	**1.41** (1.21 – 1.52)
Dietary energy kJ. 100_g^{-1}	**74.04** (71.18 – 77.17)	**99.58** (92.18 – 110.38)	**124.59** (117.37 – 128.38)
Total Carotenoids mg. 100_g^{-1}	**4.47** (2.04 – 7.01)	**3.26** (2.96 – 3.33)	**113.38** (86.97 – 158.57)
Losses			
Physical losses (%)	**14.56** (12.50 –18.16)	**21.21** (13.64 – 30.30)	**17.93** (13.72– 22.11)
Physical loss ($x10^3$ t)	**37.20** (31.94 – 46.41)	**26.92** (15.73 – 34.96)	**15.25**(11.67 – 15.27)
Economic loss ($x10^6$ t)	**61.64** (33.99– 99.75)	**17.74** (8.35 – 28.85)	**21.71** (15.32 – 24.81)
Environmental impacts			
GHGE ($x10^6$ t) $CO_{2eq.}$	**13.77**(11.82 – 17.17)	**2.94** (1.89 – 4.20)	**1.37** (1.05– 1.69)
Energy loss ($x10^6$ MJ)	**111.63** (98.83 – 139.23)	**26.92** (17.31 – 38.46)	**14.79** (11.32 – 14.81)
Fresh water loss ($x10^6$ m^3)	**4.35** (3.74 – 5.43)	**3.96** (2.55 – 5.66)	**3.74** (2.11– 3.74)

*Based on DAFF (2010abc)
Bolded values represent **mean** for all three retail outlets, the brackets provide the minimum and maximum values of the mean

vegetables vary for most vegetables. Comparing the three vegetables, carrots have the highest (245 $m^3.kg^{-1}$) water foot print followed by tomatoes (116 $m^3.kg^{-1}$) and cabbages (62 $m^3.kg^{-1}$), respectively (Mekonnen & Hoekstra, 2011). Nevertheless, the estimated overall volume of tomato produce lost per annum was by far larger than that of carrots. As a result, it is the tomato losses which contributed to higher fresh water losses (4.35 million m^3) compared to that for cabbage (2.94 million m^3) and carrots (1.37 million m^3). The estimated fresh water lost in production and marketing of the wasted vegetables could meet the daily requirements of at least 75 158 000 individuals for a whole year given that a person needs at least 0.05 m^3 of water per day (Gleick & Iwra, 1996).

The energy usage according to Mekonnen & Hoekstra (2011) for tomato production and marketing is at approximately 3 $MJ.kg^{-1}$ which is three times that for both cabbage (1.10 $MJ.kg^{-1}$) and carrots (0.97 $MJ.kg^{-1}$). In the year 2009 South Africa is estimated to have consumed 223.52 billion kWh (~804.67 billion MJ) of energy. The energy cost of the combined vegetable lost account for less than 1% of the total energy consumed. This energy loss seems very little low in percentage terms. However the value of the energy lost is worth at least R5.86 – 40.46 million given that Eskom charges a minimum energy fee of R0.75 per kWh (IEA Statistics, 2011; Eskom, 2012). Furthermore, the standard urban house hold fixed tariff of electricity consumption is 200 kWh/month therefore at least 22 000 – 153 000 urban households could benefit from the energy losses for a whole month.

This study reveals the importance of using percentage physical losses to determine the magnitude of produce lost. the value of the losses in economic and nutritional terms can then be quantified. The GHGE, water and energy involved with the losses can also be understood. This represents a holistic picture of how huge the losses are on the ground and the urgent need to mitigate the losses. A more comprehensive postharvest data review would however require that the losses be mapped across the entire supply chain. The process may be time and capital intensive but the percentages obtained can go a long way in effectively reducing postharvest vegetable losses as well as creating their awareness.

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